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# GEOLOGIC OVERVIEW, COAL DEPOSITS, AND POTENTIAL FOR METHANE RECOVERY FROM COALBEDS POWDER RIVER BASIN,

DRAFT

BY

RAOUL CHOATE
AND
CAROL A. JOHNSON

TRW ENERGY SYSTEMS GROUP
DENVER FIELD OFFICE
LAKEWOOD, COLORADO

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# 1. SUMMARY

The Powder River Basin contains the most important coal deposits in the United States. Because of their size and availability, these deposits, by themselves, could make up the entire near- and intermediate-term energy shortfall of the U.S. This statement is deliberately made to stress the critical significance of these deposits. This significance is due to their great size, the number and thickness of individual beds, their relatively shallow depth, and their occurrence in an area of relatively low land value and easily mitigated environmental constraints. Following is a summary of the geology, coal deposits, and coalbed methane drainage potential of the basin.

The Powder River Basin is an elongate north-northwest trending basin in the Great Plains Physiographic Province of eastern Montana and Wyoming. It lies within a semiarid region where vegetation is sparse and, in places, barren. The topography is characterized by steep-walled drainage channels, ridges, buttes, and local badlands. Many of the coalbeds have burned along their outcrop, forming layers of baked rock and clinker, which cap the ridges and divides. Because of the badland topography, poor soils, arid climate, sparse population, and distance from major population centers, Powder River Basin land has low economic value.

Extensive geologic mapping has been performed in the Powder River Basin in recent years. Many of these map references are compiled into lists which are included in the appendices to this report.

Sedimentary deposition in the region now occupied by the Powder River Basin prior to Late Cretaceous time, was controlled by regional tectonic features that extended well beyond the present basin confines. Rocks of this time period consist of marine sandstones, shales, carbonates and evaporites. Beginning in Late Cretaceous time, a thinner, locally controlled sequence of continental deposits formed contemporaneously with the onset of the Laramide Orogeny and the final retreat of the seas. The Laramide Orogeny dominated the structural formation of the Powder River Basin as it now exists. During early Tertiary time, block faulting of Precambrian basement rocks gave rise to the Bighorn Mountains on the west and formation of Powder River Basin on the east. At the same time, the overlying Paleozoic and Mesozoic sedimentary rocks were drapefolded over the more rigid underlying Precambrian blocks.

The general structural configuration of the younger continental coal-bearing formations is one of a gentle, asymmetrical syncline or trough, trending NW-SE, parallel to the Bighorn Mountain front. The deepest point along the structural axis is situated near Kaycee, 40 miles south of Buffalo in the Sussex Coal Field. However, during Tertiary time, when most of the coalbeds were formed, the locale of greatest subsidence and deposition was the Buffalo-Lake De Smet area. Rocks of Late Cretaceous and Tertiary age reach a maximum thickness of nearly 8000 feet at the basin axis. These younger formations dip as much as $10\text{-}25^{o}$ along the western margin of the basin. Faults with maximum displacements of 100-400 feet occur along the western margin of the basin near the Bighorn Uplift, but are less common elsewhere in the basin.

The Powder River Basin contains the nation's largest coal resources. Most of the thick coalbeds occur in the upper member--the Tongue River Member--of the Fort Union Formation, and the overlying Wasatch Formation. These two sequences reach a maximum thickness of 3970 feet near the Buffalo-Lake De Smet area; however, most of the large and more extensive coalbeds occur east of the structural axis, at depths less than 2500 feet. Coalbeds do occur in the lower members of the Fort Union Formation, as well as the Lance and Mesaverde Formations, but they are generally thinner and less continuous. Some of these older coalbeds crop out in the southwestern portion of the Powder River Basin, near Glenrock and Douglas.

In addition to the nation's largest coal resources, the Powder River Basin also contains significant accumulations of oil and gas in Paleozoic and Mesozoic rocks and deposits of uranium in Cenozoic rocks. The Powder River Basin is the most active portion of the Rocky Mountain area in terms of oil and gas exploration and production. Most current drilling by oil companies has been in Cretaceous rocks, which can range from surface exposures to 12,000 feet or more in depth. (In contrast, most exploratory efforts for uranium are restricted to shallow drilling of the younger Tertiary sequences). Since most oil and gas drilling penetrates possible coal-bearing formations, "piggyback" experiments, in cooperation with oil drilling companies, is a feasible method of studying many of the coal seams. Most exploratory drilling for uranium would be too shallow for this purpose.

The Coal resource of the Powder River Basin has been calculated from subsurface data to be 1.3 trillion tons. Most of it is in thick beds which are relatively near-surface--with most of the coal at a depth less than 2500 feet, even in the basin center.

Powder River Basin coal ranges in rank from lignite A through subbituninous A. Generally, Powder River Basin coals are low in sulfur with low to moderate ash contents, although ash content can vary considerably. Commonly, the coals have an as-received moisture content of 20 to 30 percent, and volatile matter and fixed carbon contents of 30-40 percent. The coal is non-coking and non-agglanerating. It loses moisture, slacks, and can ignite spontaneously when exposed to air.

The total number of coalbeds in the Powder River Basin is difficult to determine because the beds split, coalesce, and are sometimes discontinuous, with beds pinching out and new beds appearing. Some correlations between the beds of various fields have been made, but much remains to be done in this respect. In the Sheridan area of Wyoming, as many as 11 persistent coalbeds occur in the Wasatch Formation. In other areas, as many as 12-18 coalbeds occur, most of them within the Fort Union Formation. Most of the Wasatch beds occur under less than 200 feet of overburden. However, the Wasatch and Fort Union Formations together reach a maximum thickness of 3970 feet in the Buffalo area.

Two of the largest coalbeds in the basin are the Wyodak-Anderson and the Lake De Smet beds. The Wyodak-Anderson coalbed crops out over a north-south distance of 120 miles in the Gillette Coal Field. It, and the beds correlative to it, persist downdip to the deepest part of the Powder River Basin. The Wyodak-Anderson bed is locally up to 150 feet thick, but averages 50 to 100 feet in thickness. Based on these figures, the bed contains at least 100 billion tons of coal to a depth of 2000 feet. This is the largest tonnage in a single continuous coalbed anywhere in the U.S.

The Lake De Smet bed, which occurs in the Buffalo Coal Field, is thought to be the thickest coalbed in the U.S. and second thickest in the world. It is 15 miles in length, 70 to 220 feet thick and one-half to two miles wide.

There are 14 active coal mines in the Powder River Basin. Another 20 mines are in various stages of permit and construction. Most of these are in the Gillette area of Campbell County, Wyoming, making it the nation's coal-energy capital. The population of the Gillette area reflects this energy boom, having risen from 7,194 in 1970 to 23,500 in 1979, and expected to reach as many as 43,500 by 1990.

Al 1 ddta collected to date indicate that the Powder River Basin should provide several favorable target areas for recovery of methane gas from coalbeds by use of shallow drill holes.

The area considered in this report as the prime methane exploration target within the Powder River Basin is discussed below. It encompasses portions of Campbell, Sheridan, and Johnson Counties in Wyoming and Big Horn and Powder River Counties in Montana. Factors used in delimiting the target boundaries include:

A. Restricting the area to lands underlain by the Tongue River Member of the Fort Union Formation, and additionally to

B. Areas in which shallow drill holes are known to flow anomalously large amounts of methane,

c. Areas in which flowing artesian wells are concentrated, or

D. Areas in which three or more individually thick coalbeds are coalesced together into a single superbed.

Fifteen shallow drill holes or wells have been identified to date in Campbell County as having contained anomalously large amounts of methane in product fluids. These holes were drilled either as water wells for local use or as shallow investigations of near-surface coalbeds (less than 500' depth); none were drilled for the basin's much deeper-lying oil and gas deposits. Fourteen of these wells are in the Recluse area of northeastern Campbell County and define a NW-SE trending elliptical area approximately 33 miles long and 16 miles wide. The fifteenth well is 50 miles to the south, 25.5 miles south of Gillette.

In at least three centers of deposition within the basin, individual coalbeds are coalesced into massive "superbeds". These three centers are the Decker area, containing the 80-foot thick Anderson, Dietz No. 1 and Dietz No. 2 beds; the Lake De Smet area, containing the 220-foot thick Lake De Smet bed; and the Gillette area, containing the 125-foot thick Wyodak-Anderson bed.

The methane recovery target area at Recluse, defined by drill hole, occurs at the margin of one of these depositional centers where a superbed splits into two or more component seams. At such locations, methane gas release from the coal seams, and collection within interbedded coal seam and porous sandstone sequences, may be optimal. Identification of such natural gas collection traps should be useful for indicating areas within the Powder River Basin where underlying coalbeds could have anomalously large amounts of adsorbed methane.

Many flowing artesian wells occur within the Powder River Basin, and several of them are known to contain substantial amounts of natural gas. Origin of this gas is the coalbeds and carbonaceous zones in the Fort Union Formation. It has been shown that gas in an aquifer increases the height to which water rises in a well and can create a flowing artesian well by raising the water to the surface. This lifting action is created by expansion of the gas as pressure is reduced in water flowing from the aquifer. Because of this lifting action, some portion of the artesian wells in the basin flows that otherwise would not do so.

If one assumes that some significant--but as yet unknown--portions of the flowing artesian wells flow because they are tapping coalbeds with anomalously high methane content, then such artesian wells might serve as a useful exploration aid. Hydrologic maps covering the Powder River Basin show locations of at least 198 flowing artesian wells within the boundary of the Fort Union Formation. A non-random distribution of the wells has been determined, 68 being in the eastern half of Sheridan County, 71 in northeastern Johnson County, 29 in the northern half of Campbell County, and 16 located mostly in two separate areas in Converse County. Of the flowing artesian wells in Sheridan and Johnson Counties, at least five are known to contain methane.

Of the flowing artesian wells in Sheridan, Johnson, and northern Campbell Counties, most are located along the major drainages of Tongue River, Powder River, and two principal tributaries of the Powder--Little

Powder River and Clear Creek. The drainage system of the Powder River Basin is thought to be controlled by two fracture systems. The dominant fracture set is parallel to the northwest-southeast trend of the basin axis, and the secondary set is approximately perpendicular to the basin axis. Location of four of the artesian wells known to contain methane, along the Powder River south from Clear Creek, and one well near the Tongue River provides tentative evidence that free methane is more abundant in fractured coal-bearing strata adjacent to structurally controlled drainage channels than it is in land areas between such channels.

Within the regional target delimited on the map (Figure 1-1), smaller initial target areas can be defined based on probable structural and stratigraphic controls, including the following:

1. Major drainage channels that parallel any of the known fracture sets, especially those channels along which flowing artesian wells are concentrated.

2. Secondary channel ways with anomalously linear development parallel to the major, NW-SE or NE-SW fracture-set directions and along which are located flowing artesian wells or shallow-drill holes known to emit methane.

3. Zones along anticlinal fold axes, where rocks under tensional stress could be more highly fractured than rocks on fold limbs. Anticlinal crests present highly favorable zones where fractured rocks can act as hosts for methane migrating updip from coalbeds along fold limbs.

4. Zones along synclinal fold axes where methane desorbed from coal-particle surfaces can collect in open fractures.

5. Stratigraphic traps created where superbeds split into two or more individual coalbeds.

6. Coalbeds in the deeper portion of the basin, paralleling the basin synclinal axis. Adsorbed methane concentration should be greatest in such beds because of the greater hydrostatic pressure and the probable higher coal rank in more deeply buried coals.

7. The northwest trending, 33-mile long, elliptical area in Campbell County in which shallow drill holes flowing methane gas are concentrated. Geologic controls for this concentration probably are partly structural and partly stratigraphic.

Initial individual drill sites for collecting coalbed methane data could include:

a. Sites beside holes known to flow methane or beside flowing artesian wells containing methane,

b. Sites on the crests of small structural closures along fold axes, and

c. Sites at the intersections of two or more favored linear structural features; e.g., the intersection of a fold axis and a linear stream channel or the intersection of two linear stream channels such as the conflux of Powder River and Clear Creek.

It is important to determine if methane gas can be practicably collected from shallow Powder River coalbeds as quickly as possible. These coalbeds are the principal target of the great strip mines being put into operation along the northwestern and entire eastern rim of the basin. As these pits are opened, any methane contained within and adjacent to stripping areas will be lost to the atmosphere. If such methane gas is to be salvaged, the operation must occur before new pits are opened and the entire rim of the Powder River Basin coal seams is exposed to updip migration of methane contained in the deeper, more central portion of the basin.

An initial program here recommended for investigating methane recovery potential of the Powder River Basin, includes:

1. Construction of a lineation map of the basin from topographic and geologic maps, from spacecraft synoptic imagery, and from aerial photographs.

2. Collection of all data possible from the literature, from geotechnical personnel currently working in the basin, and from local water-well drillers, concerning methane content encountered in drill holes and water wells.

3. Field measurements of fracture systems in coal-bearing strata of the central Powder River Basin.

4. Collection of well-bottom samples from both flowing and non-flowing artesian wells in the central Powder River Basin and measurement of contained methane.

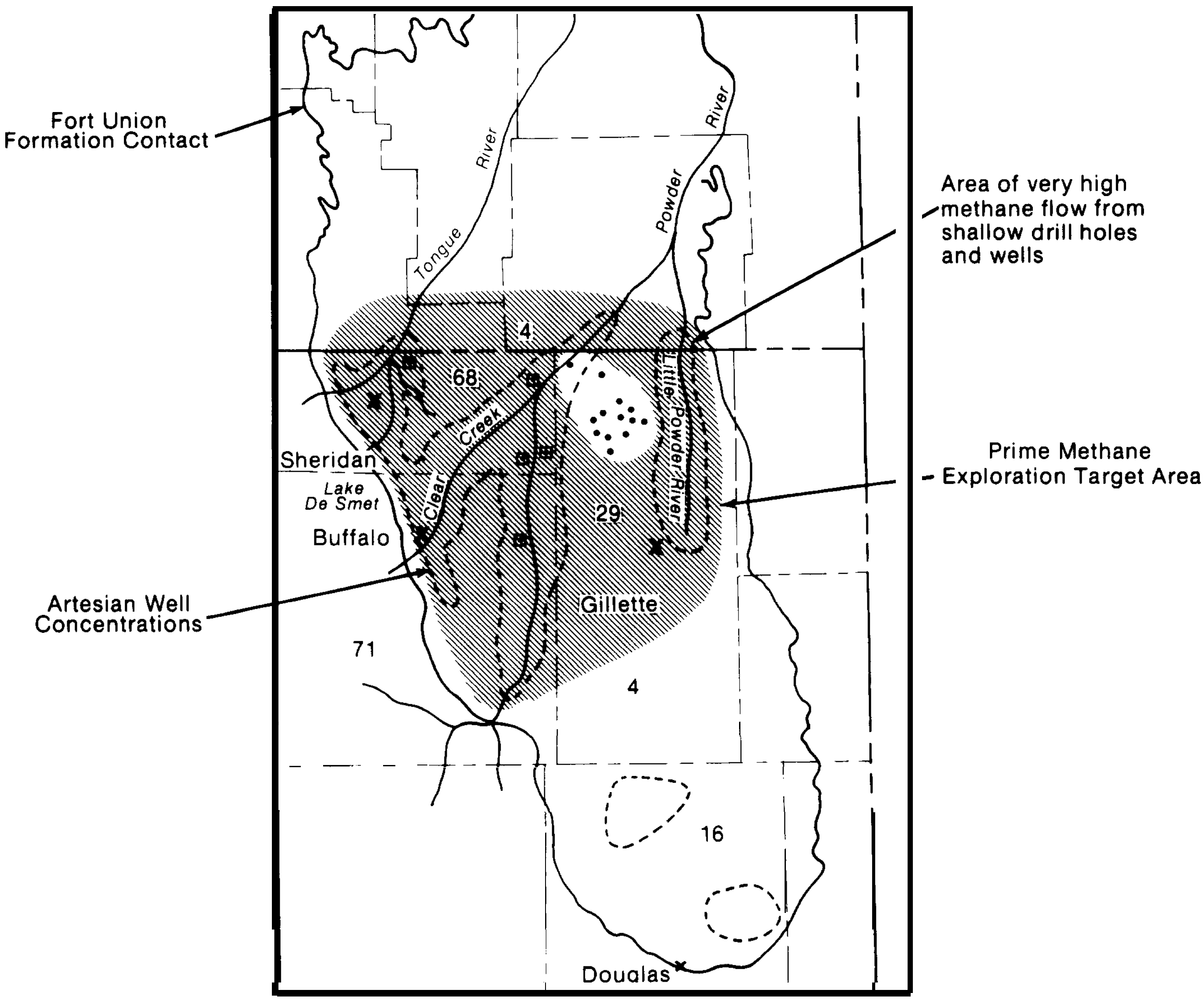
5. Cooperation with the U.S. Geological Survey, the Montana Bureau of Mines and Geology, and the Wyoming Geological Survey in collection Of coal core samples during their shallow-to-intermediate

depth drilling programs (generally less than 1000-foot depths), and performing methane desorption tests.

6. Performing "piggyback" tests with companies exploring for oil, gas and uranium, in collection of coal core samples for methane desorption tests..

7. Performing intermediate-to-long term gas-flow tests on selected shallow holes drilled either for the U.S. Geological Survey or Montana Bureau of Mines and Geology programs or drilled specifically for the Methane Recovery from Coalbeds Project. This task is especially important for the Powder River Basin because the low-rank coal samples collected by coring may be so porous as to lose essentially all adsorbed methane before the samples can be placed in sealed canisters at the surface.

8. Drilling of small anticlinal highs with three to five dewatering wells around the base of the high and one methane collection well at the top.




• Shallow Drill Hole with Anomalous Methane Content

⊡ Flowing Artesian Well with Methane

4 Number of Flowing Artesian Wells in Area

**Figure I-I** Methane Exploration Target Area in Tongue River Member of the Fort Union Formation, Central Powder River Basin (Duplicate Figure 6-1 of Conclusions).

# 2. INTRODUCTION

The objective of this report is twofold: 1) summarize the general geology and occurrence of coal in the Powder River Basin of Wyoming and Montana; and 2) compile all existing information on the occurrence of methane associated with the coalbeds, identify areas of anomalously large amounts of methane, and define target areas for investigating the methane recovery potential.

The report is organized into four main parts. General geology of the Powder River Basin is summarized in Chapter 3, with younger sedimentary sequences discussed in greater detail, as they contain most of the larger coalbeds. The end of Chapter 3 includes a brief description of other energy resources of the Powder River Basin, namely uranium, oil and gas. Principal coal fields and coalbeds are described in Chapter 4. When possible, references have been included on extent, thickness and quality of the coal. Chapter 5 compiles all known occurrences of methane in coalbeds in the Powder River Basin. Identification of methane exploration target areas and recommendations for further work are outlined in Chapter 6. Chapter 7 lists references cited within the text, and Chapter 8 gives additional references of possible reader interest. There are three Appendixes to this report including topographic and land ownership maps covering the Powder River Basin (Appendix A), references to geologic mapping in the Powder River Basin as indexed by the USGS (Appendix B), and selected references to recent mapping in the Powder River Basin (Appendix C).

# 3. BASIN SETTING

## 3.1 GEOGRAPHIC SETTING

### 3.1.1 Geography

The Powder River Basin is an elongate, northerly trending inter-montane basin lying between the Black Hills on the east and the Bighorn Mountains on the west (Figure 3-l). Bounding the basin on the north, in Montana, is the Yellowstone River and on the south, in Wyoming, the North Platte River (Figure 3-2). The basin boundary assumed for this report is that used by Keefer and Schmidt (1973) on their "Energy Resources Map of the Powder River Basin, Wyoming and Montana," (in pocket following Figure 3-2).

The basin, situated between the flanks of two major mountain ranges, resembles a dumbbell in shape (Figure 3-2). Its geographic axis, bearing N15$^{\circ}$W, lies approximately 7 miles east, of and roughly parallels, the straight line connecting Forsyth, Montana, on the Yellowstone River and Douglas, Wyoming, on the North Platte.

The basin has a maximum length, along its longitudinal axis, of 256 miles and an average length of approximately 228 miles. Maximum, minimum, and average widths of the basin are 132, 94, and 115 miles, respectively. Basin area is approximately 25,800 square miles.

### 3.1.2 Physiography

The Powder River Basin is a north, northwesterly trending basin in the Great Plains Physiographic Province. The major structural features of the basin were formed during the Laramide Orogeny of Late Cretaceous and Early Tertiary time. The deeply synclinal structure is not reflected in the topography. Most topographic features are a result of differences in erosional characteristics of the Tertiary rocks, stream erosion, and subsidence due to the burning of coal seams. The smaller stream channels are parallel to a N35$^{\circ}$W fracture system resulting in a northwest-trending grain in the topography (Mapel, 1959). Many small streams have carved the soft shale and sandstone into local badlands. The natural burning of coal seams has formed many resistant baked rock and red clinker layers which cap ridges and divides.

Average surface elevation in the Powder River Basin is 5000 feet. Relief ranges from 3700 feet in the valley of the Powder River to 5700 feet in the foothills of the Bighorn Mountains. The summit of Cloud Peak in the Bighorn Mountains is at 13,175 feet.

Because of the badland topography, poor soils, arid climate, sparse population, and distance from major population centers, most of the land in the Powder River Basin has low economic value.

### 3.1.3 Climate

The Powder River Basin lies within a semi-arid region of pronounced seasonal variation in temperature and precipitation. Vegetation is sparse-- in places, barren--and consists of grass, sagebrush, and prickly pear, with willows and cottonwoods along the valley bottoms. The annual rate Of evapotranspiration exceeds the area's rainfall, resulting in drought conditions and a short growing season. Irrigation is therefore necessary to revegetate strip mined areas (Toy and Munson, 1978).

Mean annual precipitation shown in Figure 3-3 ranges from a low of 9.2 inches at Dead Horse Creek near the basin center, to a high of 20.2 at station Kirby 1S in the northwest. In general, precipitation is higher in the basin's northern portion.

Mean monthly precipitation for 12 stations in the basin area, shown in Figure 3-4 indicates that annual rainfall peaks in the spring-midsumner months at 2-4 inches per month, and decreases to less than one inch per month during winter. The relatively low precipitation during July and August compounds the problem of revegetating strip mined areas.

Precipitation varies greatly from area to area. Particularly noticeable is the Dead Horse Creek Station which receives 9.2 inches annually; however, only 10-12 miles to the east, Gillette 18°SW Station receives 16.1 inches. This variation may be attributed to a rainshadow effect of the Bighorn Mountains.

Temperature varies with altitude and season. Summer temperatures range from a mean minimum in July of 36 to 60°F, with the lower temperatures occurring in the Bighorn Mountains. Mean maximum for July ranges from 72 to 90°F, again, with the lower temperatures in the mountains. Winter temperatures range from a mean minimum in January of 0 to 12°F.

Mean maximum for January ranges from 28 to 36°F. (Dightman, 1960; Lowers, 1960). Normals, means, and extremes for temperature, precipitation, relative humidity, wind, and sunshine over a 30-year period for three cities are shown in Table 3-1 (National Oceanic and Atmospheric Administration, 1977, 1978).

### 3.1.4 Mapping Status

Extensive mapping has been performed in the Powder River Basin in recent years. Selected recent map references, as well as the older references, have been compiled into lists which are included as Appendices to this report. This compilation was not intended as an exhaustive literature search, but includes most of the work done in the Powder River Basin by the USGS and the state surveys of Montana and Wyuning. The following is a brief summary of this compilation.

Indexes to available U.S. Bureau of Land Management maps and U.S. Geological Survey topographic maps (Figures A-1 through A-4) for the Powder River Basin are given in Appendix A.

Appendix B contains references to earlier geologic mapping in the Powder River Basin (1859-1970) taken from four separate USGS state indexes to geologic mapping for Montana and Wyoming. The USGS indexes are out of print but updated versions are included in Appendix B of this report.

Appendix C contains selected references to recent mapping (1970-present) in the Powder River Basin, compiled by the authors of this report. Map lists are divided into three groups according to subject matter and scale. Appendix C-1 includes references to regional coal studies and regional geologic mapping at various scales. Appendix C-2 contains references to recent 7-1/2' quadrangle maps by the USGS--all at 1:24,000. These include geologic maps, coal resource and developent potential maps and surficial geology maps. Appendix C-3 contains references to various maps, charts and geophysical logs. These are grouped according to subject matter into four separate lists, including miscellaneous geological maps, land use maps by the USGS, geophysical maps and logs by the USGS, and stratigraphic charts and sections by the USGS and U.S. ERDA.

The agency holding negatives and indexes for all aerial photography and spacecraft imagery is the EROS Data Center at Sioux Falls, South Dakota,* or the National Cartographic Information Center (NCIC) at the Denver Federal Center.

## 3.2 CULTURAL FEATURES

Counties wholly or partially encompassed within the basin include Campbell, Converse, Sheridan, Johnson, Weston, Niobrara, Crook, and Natrona in Wyoming; and Powder River, Big Horn, Rosebud, Custer, Treasure, and Carter in Montana (Figure 3-2).

Major towns within the basin boundary are Casper (population 39,361' - 44,000**) Gillette (7,194+ - 23,500**), Sheridan (10,300+ - 13,710**) Buffalo (3,394') and Douglas (2,677+)--all in Wyoming. Towns just outside the basin boundary include Newcastle (3,432+), Wyoming, to the southeast; and Miles City (9,300**) and Forsyth (1,873+), Montana, to the north, on the Yellowstone River (Figure 3-2).

The area is serviced by the Burlington Northern Railroad. A new 116-mile line connecting the towns of Reno and Orin, Wyaning has been completed (see Figure 3-5). Many highways and secondary roads crisscross the basin. The major interstate highways are I-90, I-25 and I-94.

The Powder River Basin is the most active area in the Rocky Mountain region in terms of oil and gas production. A number of major oil and gas pipelines cross the area.

Gillette, situated in the center of the basin in Campbell County, Wyaning, has beccme the coal-energy capital of the nation with seven operating coal mines in the region, three mines in development stages, and seven more in permit stages. The energy boom is reflected in the population

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*Address: EROS Data Center
U.S. Geological Survey
Sioux Falls, South Dakota 57198
Phone: (605) 594-6511

+1970 Census

**Campbell County Chamber Commerce (1979) and Sheridan County Chamber Commerce (1978).

growth of the Gillette area (see Table 3-2), which has increased from 7,194 in 1970 to 23,500 in 1979. Roughly 10 percent of the total population is employed in the coal industry. Coal contributed 13.60 percent to the assessed valuation of Campbell County in 1978; up from 0.93 percent in 1974. Oil and gas contributed 64% to the 1978 valuation, down from a high of 83% in 1975.

## 3.3 GEOLOGY

### 3.3.1 Basin Structure of a Regional Nature

Powder River Basin is an elongate northerly trending structural basin lying along the eastern front of the Middle Rocky Mountains (Figures 3-6 to 3-10). When considering the entire sequence of sedimentary rocks deeply buried in the basin, it is probably most accurately visualized as a broad, flatbottomed, but slightly tilted, structural trough downwarped between the Bighorn Uplift on the west and the Black Hills Uplift on the east (Figures 3-8 and 3-9).

Older sedimentary rocks--those older than Late Cretaceous--have relatively steep dips on both margins of the basin. Along the Bighorns, average dip of the sedimentary rocks ranges mostly from 10-55 degrees, with average dip of the base of the sedimentary sequence (Precambrian contact) being 12 degrees. Along the Black Hills, dip generally ranges from 5 to 25 degrees, with average dip of the base of the sequence being 5.4 degrees (Figure 3-8). Locally, dips along basin margins are much steeper.

Across the broad central portion of the basin, however, all sedimentary rocks have essentially uniform shallow dips to the west that range mostly from 0.3 to 1.5 degrees. For the base of the sedimentary sequence, this regional dip is an average 1.1 degrees and extends from the base of the Black Hills, westward 75 miles to the deepest portion of the basin, close to and just east of the front of the Bighorn Mountains (Figure 3-8). This western edge of the above described trough is considered the structural axis of the basin. The marine strata, up to the beginning of the Laramide Orogeny, are all remarkably conformable with average regional dips ranging between 1.1 and 1.3 degrees (Figure 3-8). With retreat of the marine seas during early Laramide uplift, rocks of continental origin deposited during Late Cretaceous and Early Tertiary times show progressively shallower regional dips. For example, the Wyodak coalbed--whose upper surface in recent USGS mapping acts as the contact between the Paleocene Fort Union Formation and the Eocene Wasatch Formation--has a regional dip of only 0.4 degrees over an east-west distance of 25 miles (Figure 3-8). The structural form of these younger, non-marine rocks is that of a very gentle asymmetrical syncline (Figure 3-8). At the basin axis, thickness of these rocks is nearly 8,000 feet (Curry, 1971).

Laramide structural movements are considered by Curry (1971)--based on isopach maps constructed from electric-log data--to have commenced after deposition of the Lewis Shale (early Maestrichtian time) and to have mainly ceased before deposition of the White River Formation of Oligocene time. A summary of Laramide structural events is given in Table 3-3.

The Powder River Basin is only one of a line of basins that lie along the entire front of the Rocky Mountains, extending from northern New Mexico to central Montana. In general, these basins--especially the Denver Basin to the south, which is separated from the Powder River Basin by the Hartville Uplift--have similar asymmetries in that their structural axes lie very close to the Rocky Mountain front. Of these basins, the Powder River is the deepest, containing in excess of 18,000 feet of sedimentary rocks. At Buffalo, Wyaning, structural relief of the Precambrian surface across the mountain-basin interface is in excess of 25,000 feet. This relief occurs in a horizontal distance of only 25 miles, extending from a height of 13,175 feet above sea level at Cloud Peak in the Bighorns to a depth greater than 12,000 feet below sea level at the basin axis. This interface probably represents a boundary between two continental subplates. Thus, with the onset of the Laramide Orogeny in Late Cretaceous time, rise of the modern Rocky Mountains occurred at the margin of the western plate concurrent with downdrag along the margin of the eastern plate, causing formation of the line of basins along the front.

### 3.3.2 Basin Stratigraphy

Sedimentary rocks within the Powder River Basin are of two basic types--an older, thick contiguous sequence of Paleozoic and Mesozoic rocks mostly of marine origin, and a younger thinner sequence of Late Cretaceous and Cenozoic rocks of continental origin whose deposition began with the final retreat of the marine seas during regional uplift accompanying onset 'of the Laramide Orogeny (Figure 3-11).

These rocks will be discussed in eight units representing major transgressions of the marine seas in the area, each unit being separated by a major unconformity. Rock Unit VIII, which includes all beds of Tertiary age, will be discussed in greatest detail as it includes most of the economic coal-bearing strata.

3.3.2.1 Pre-Coal Marine Deposits

Sedimentation in Powder River Basin was controlled by regional tectonic features prior to Late Cretaceous time. During Paleozoic time the Powder River Basin area was part of a sedimentary shelf, bounded by the Paleocordilleran Trough to the west and the Transcontinental Arch to the east. Marine seas transgressed the area generally from west to east. The following description is summarized from an article by the Wyoming Geological Association (1965).

Rock Unit I. The first Paleozoic sea encroached the northwest area of the Powder River Basin during Middle Cambrian time, covered the entire basin by Late Cambrian time and regressed during the close of Early Ordovician time. The formations include sandstones with minor shales of the Flathead Formation, which grade upward into shales of the Gros Ventre Formation and finally carbonates of the Gallatin Formation. These formations thin eastward where they are referred to collectively as the Deadwood Formation. Later uplift resulted in erosion of the upper beds of Rock Unit I. Combined thickness of the Flathead, Gros Ventre and Gal latin Formations is about 900 feet in the northeast area of the basin and about 90 feet in the south. The Deadwood Formation, on the east side of the basin, is about 500 feet thick in the north and is absent in the southeast.

Rock Unit II. The second transgression of the sea occurred during Middle Ordovician time. The Powder River Basin was again positioned in a shallow marine shelf environment between the deeper paleo-Williston Basin to the north and the Transcontinental Arch on the southeast. Sedimentary rocks of Rock Unit II include the Harding Sandstone, Lander Sandstone and Bighorn Dolomite on the west, and the Aladdin Sandstone, Icebox Shale, Roughlock Slate and Whitewood Dolomite on the east. The formations thin to the east and south from 430 feet in the northwest to about 100 feet thick in the northeast, and are absent in the southern portions of the basin.

Rock Unit III. During deposition of Rock Unit III, the Powder River Basin was again the site of shallow-water deposition. The regional setting was generally unchanged. Sediments deposited during the third transgression include the Devonian sandstones, shales and limestones of the Darby Formation. Overlying these is the Madison Limestone of Mississippian age, which is divided into lower, middle and upper units, separated by two unconformities. Other members of Rock Unit III are the Madison equivalent Guernsey Formation on the southeast side of the basin and the Pahasapa Limestone and Englewood Formation in the Black Hills.

After Mississippian deposition, the area was uplifted, causing leaching and erosion of the Madison rocks. As a result, a karst topography developed on the Mississippian surface over the entire basin. The Madison ranges in thickness from about 1000 feet near the Montana/Wyoming state line to 200 feet in the southern part of the basin. The Guernsey Formation has a maximum thickness of about 300 feet in the southeast.

Rock Unit IV. The fourth transgression of the Paleozoic sea occurred during Pennsylvanian and Lower Permian time. Until this time, the sediments formed were primarily fine-grained clastics and carbonates. During deposition of Rock Unit IV, however, non-marine clastics were deposited over much of the area. The sea advanced over the basin from the southeast across the Transcontinental Arch as well as from the Cordilleran Trough in the southwest. The rocks of Pennsylvanian and Lower Permian age are called the Hartville Formation (850-1300 feet thick) in the southeastern portion of Powder River Basin; the Casper Formation in the southwest; the Tensleep Sandstone, Amsden Formation, and Darwin Sandstone Member on the west (300 feet thick); and the Minnelusa Formation on the east (700-900 feet thick). During this episode, the Ancestral Rockies in southern Powder River Basin were eroded and transgressed by the encroaching sea. Also at this time, the Montana Highlands to the northwest were rising, causing an increase in clastic sedimentation. At the termination of Lower Permian deposition, compressional stresses formed major NW-SE and minor N-S lines of folding. Subsequent erosion resulted in an irregular topography of hogbacks and cuestas.

Rock Unit V. Rock Unit V of Permian and Triassic time is comprised of sandstone, shale, carbonate and red-beds, which formed as the Phosphoria Sea advanced eastward onto the Wyoming shelf. A barrier to free circulation, built up on the west, resulted in deposition of thin evaporite layers in the basin. Formations included in Rock Unit V, on the western side of the basin, are the Goose Egg Formation, which thins northward from about 350 feet in the southwest to 180 feet at Buffalo, and the Chugwater Formation which is 800 feet thick in the northwest and 700 feet thick in the southwest. Equivalent rocks on the east side of Powder River Basin are the Opeche Shale (25-75 feet thick in the southeast), and the Spearfish Formation (450 feet thick in the Newcastle area). Eroded remnants of the Alcova, Crow Mountain, Popo Agie and Nugget Formations of Triassic age are found in the southwest portion of the basin.

Rock Unit VI. Jurassic sedimentation (Rock Unit VI) began with marine transgression from the north and west and the formation of restricted lagoons and mud flats. The Gypsum Springs Formation consisting of massive gypsum, claystone, and limestone was deposited over most of the northern Powder River Basin. Thickness ranges from 185 feet on the west to 125 feet on the east and thins southward. These sediments were not deposited in the south because of the presence of a broad, relatively high trend across the north-central basin. The second cycle of deposition, forming the lower Sundance sandstones, was also influenced by the presence of this arch. Cal careous beds of the Rierdon Formation formed to the north, while shales and sandstones of the Lower Sundance Formation were deposited to the south of the arch. Inundation continued, and sands of the upper Sundance Formation covered the whole basin. The formation is 370-400 feet thick in the east, 280 feet in the northwest and 350 feet thick in the southwest. After deposition of the Sundance, the Jurassic sea retreated and the continental Morrison Formation and Early Cretaceous Lakota Formation were deposited. The Morrison consists of claystone and interbedded fine-grained sandstone. On the east side of the basin it is 150 feet thick to absent in places, and on the west it ranges from 220 to 130 feet thick. The Lakota Formation consists of lenticular sandstone, conglomeratic sandstone, and shale. It averages 100-300 feet in thickness.

Coal crops out near the base of the Lakota Formation at several places on the eastern margin of the Powder River Basin in Crook and Weston Counties, Wyoming.

Rock Unit VII. Rock Unit VII, of Cretaceous age (Figure 3-12) was deposited following a period of regional tectonic change. Previous transgressions of the seas had been primarily from the west. Beginning in Jurassic time, the region developed into an orogenic belt which shed sediments eastward. The Early Cretaceous marine beds of this unit were deposited in a sea which encroached both from the north and south, merging in the central Rocky Mountain and Great Plains regions. The Powder River Basin, situated in the center of the seaway, received sediments from several directions. The rocks of this unit can be divided into five transgressive- regressive cycles of shales and sandstones. They include sandstones of the Thermopolis Shale on the west and the Fall River Sandstone on the east. The beds thin basinward from both sides and are absent in the west-central portion of the basin. These were followed by the Thermopolis marine shale and Skull Creek Shale which formed over the entire area. The Newcastle Sandstone on the east and the Muddy Member of the Upper Thermopolis on the west formed during the second regressive cycle. Again, the sands were deposited from the east and west sides of the basin and are absent in large irregular-shaped areas in the center of the basin. Deposition of the marine Mowry Shale followed the sandstones. The shales were formed during a period of volcanic activity and contain ash, resulting in a hard siliceous shale. The third regressive cycle is represented by the Frontier Sandstone. The source area to the east was eliminated about this time, and the Frontier Sandstone, which was derived from sediments to the west was formed only along the western margin and southwest portion of the basin. The Frontier Sandstone represents a series of five oscillating transgression-regression cycles. During this time, the Belle Fourche Shale and Greenhorne Limestone formed to the east. Deeper water then covered the entire area forming the Cody Shale, Carlile Shale and Niobrara Formation. During and after deposition of the Cody, movements in the western Cordilleran area caused periodic influxes of sandstones into the western area of the basin. These include the Shannon and Sussex Sandstone members of the Cody Shale, the Parkman and Teapot Sandstones of the Mesaverde Formation and the Teckla Sandstone of the Lewis Shale. These are equivalent to the Pierre Shale on the east. Coals are reported from the 500 foot thick Mesaverde Formation in the southwestern portion of the basin. They are described variously as clean, dirty or shaly beds, generally less than one foot thick although a few beds are up to three feet thick, locally (Glass, 1976). The repeated transgressions and regressions are apparently related to the beginning of the Laramide Orogeny (Wyoming Geological Association 1965).

3.3.2.2 Coal-Bearing Continental Deposits

The final retreat of the sea was followed by formation of continental deposits of Late Cretaceous age (Figure 3-13). These are called the Lance Formation in Wyoming and the Hell Creek Formation in southeast Montana. These two formations consist of alternating, massively bedded sandstone and dark-colored claystone and shale. The formations thicken southward from 500-600 feet in Big Horn County, Montana, to 2500 feet in Converse County, Wyoming. Although evidence of Laramide deformation is present in rocks of this age in other areas, there is no evidence in the Powder River Basin of the Laramide Orogeny during Lance time. The basal part of the Lance Formation contains small, local beds of impure coal in the southwestern part of the Powder River Basin. Some of the coal seams are reported to average three to six feet in thickness (Mapel, 1958; Curry, 1971; Glass, 1976).

Rock Unit VIII. Early Tertiary time began with a large influx of sediment into flood-plains, estuaries and swamps of the newly formed Powder River Basin. The open sea was to the east and northeast. The stratigraphic position of the Cretaceous-Tertiary boundary has been disputed over the years. It is now generally accepted, however, that Tertiary rocks begin with the "lowest persistent bed of lignite" found directly above the latest dinosaur remains (Calvert, 1912; Brown, 1958; Matson and Pinchock, 1976).

Tertiary rocks covering most of the Powder River Basin are the Fort Union Formation of Paleocene age and the Wasatch Formation of Eocene age. Fort Union and Wasatch time was characterized by cyclic deposition in a near-shore environment that was periodically undergoing uplift and subsidence. During periods of stability extensive coal-forming swamps developed. Obernyer (1979) has described the Fort Union and Wasatch Formations from outcrops along the western margin of the basin in the Lake

De Smet area. In this area, Obernyer considers the conglomerate member of the Fort Union and the Kingsbury Conglomerate and Moncrief Gravel Member of the Wasatch products of an alluvial fan fronting the Bighorn Uplift. These coarse-grained deposits give way eastward to fine- and medium-grained sandstones, siltstones, mudstones, claystones and thick coals of an extensive alluvial plain environment. Bryson and Bass (1973), in describing the Moorhead Coal Field to the northeast, state that the Tongue River Member consists of an alternating sequence of massive, faintly-crossbedded sandstone, 40-100 feet thick, overlain by a thin layer of shale and clay, a thick coalbed, and finally shale and other rocks of varying thickness. These sedimentary sequences are thought to have formed in an extensive flood-plain envirorrnent, with the open sea to the east and northeast. The thick sandstone beds were probably deposited in littoral environments and the principal coalbeds formed in large coastal swamps and marshes.

The source area was to the west-northwest; with the Fort Union and Wasatch differing in lithology and thickness from place to place. These units are described by Lewis and Roberts (1978) and Denson and Horn (1975) as follows from the northern and southern parts of the basin, respectively:

o Northern Powder River Basin

WASATCH FORMATION (O-400 ft or O-120 m) -- Brownish gray to light-gray fine- to coarse-grained lenticular beds of sandstone and interbedded gray shale and coal. Contains a fossiliferous zone of clams and snails as much as 30 feet (9.1 m) thick. Zones of clinker crop out along the coal horizons. Base of unit is mapped as the top of the thick and persistent Roland coalbed, as defined by Baker (1929). Conformable contact with underlying unit.

FORT UNION FORMATION

Tongue River Member (O-2,500 ft or O-760 m) -- Light-yellow to light-gray fine- to medium-grained thick-bedded to massive locally crossbedded and lenticular, calcareous sandstone and siltstone; weathers to a buff color. Commonly contains light buff to light-gray shaly siltstone and shale, and brown to black carbonaceous shale. Contains nunerous coalbeds; as much as 80 feet (24 m) thick. Burning of the coal along outcrops has formed thick red and lavender clinker and baked shale beds. Base of unit is mapped as the change from predominantly siltstone and sandstone to predaninantly shale of underlying unit.

Lebo Shale Member (O-600 ft or O-180 m) -- Predominantly dark shale containing interbeds of light-gray and brown to black carbonaceous shale, siltstone, and locally thin coalbeds. Shales contain altered and devitrified volcanic ash and brown ferruginous concretions. Base of unit is mapped as the change fran predominantly shale to predominantly fine-grained sandstone and shale of underlying unit. Conformable contact with underlying unit; however, the Lebo exists locallv as scoured channel deposits developed well into the Tullock Member:

Tullock Member (0-800 ft or 0-240 m) -- Lower part of member is interbedded medium-gray to light-gray shale, fine-grained light-gray sandstone and siltstone, and thin but persistent coalbeds; grades upward to light-gray carbonaceous shale. Locally at the top is a resistant sandstone that forms a well-developed rimrock. Base of unit is mapped as the change from fine-grained thin-bedded sandstone, siltstone, shale, and coalbeds to predominantly massive channel sandstone and dark-gray shale of underlying unit (Brown, 1952; Dunlap, 1958).

o Southern Powder River Basin

WASATCH FORMATION (LOWER EOCENE) -- Gray, brown, and reddish-pink conglaneratic to fine-grained arkosic sandstone, siltstone, carbonaceous shale, and coal; all of fluviatile and paludal origin. In general, the sandstone is coarser grained and contains two to three times more heavy minerals than those in the underlying Tertiary rocks. Conglomerate, 2-4 feet (0.6-1.2 m) thick and composed primarily of black chert pebbles, is present locally at the base. Unconformably overlies the Lebo Member of the Fort Union Formation. Contains some of the largest coal and uranium deposits in the Powder River Basin. 0-1,800 feet (0-549 m) thick.

LEBO MEMBER OF FORT UNION FORMATION (PALEOCENE) -- Light- to dark-gray very fine grained to conglomeratic sandstone interbedded with varying amounts of siltstone, claystone, carbonaceous shale, and coal; all of fluviatile and paludal origin. Ganister (hard, dense quartzite) boulders and slabs containing numerous leaf and root impressions derived from beds of silicified swamp muck within the Lebo Member occur locally on the surface. Thin-bedded calcareous ironstone concretions interbedded with massive white sandstone and light- to dark-gray slightly bentonitic shale occur throughout the unit. Locally, coalbeds are more than 4 feet (1.2 m) thick. Conglomeratic coarse-grained sandstone interbedded with shale occurs in the southern and southwestern parts of the basin. In general, the sandstones included in the Lebo are finer grained and better sorted than those in the Wasatch. Also the percentage of heavy minerals in the Lebo sandstones is very low. 1,700-2,800 feet (518-853 m) thick.

TULLOCK MEMBER OF FORT UNION FORMATION (PALEOCENE) -- Interbedded sandstone, siltstone, shale, carbonaceous shale, and thin coalbeds. Sandstone is tan to buff, massive to thin, and evenly bedded. Shales generally are dark gray and brown. Distinguished from the underlying upper Cretaceous Lance Formation by the presence of thin coalbeds, the lack of dinosaur-bone fragments, and a stratified appearance due to the presence of thin coalbeds and carbonaceous shales interbedded with persistent thin to passive sandstone beds. Strike and dip measurements are easily obtainable. The drab appearance and massive sandstones of the Tullock make it easily distinguishable from the conformably overlying Lebo Member which generally has a lighter overall aspect and a predominance of siltstone and shale. 1,000-1,500 feet (305-475 m) thick.

The Fort Union crops out in a band around the margin of the basin (Figure 3-14), averaging 60 miles wide on the north, 25 miles on the east and 5 miles on the south and west sides. Structural deformation and its effects on Eocene deposition are responsible for limited exposures on the west side of the basin along the Bighorn Mountains (Obernyer, 1979; Mapel, 1958). The Fort Union, about 2100 feet thick in the east, has its maximum thickness of 5215 feet at the center of the basin (Curry, 1971; Grazis, 1977). Dips are 10 to 25$^{\circ}$ near the Bighorns and otherwise relatively flat averaging 2 to 3$^{\circ}$ (Mapel, 1958).

The Fort Union is subdivided into three members: in ascending order, they are the Tullock, Lebo Shale and Tongue River. The Tullock Member consists of friable light-colored sandstone, dark- to light-gray shale and thin beds of coal. It is as much as 1100 feet thick in the southern part of the basin and thins northward to about 200 to 250 feet in Montana. Curry (1971) states that, "Tullock deposition...marks the first evidence of Laramide deformation in the Powder River Basin." The overlying Lebo Shale Member is 150 to 400 feet thick and consists mostly of soft clay-like shale and thin beds of sandstone and siltstone which locally contain ferruginous concretions and thin beds of coal. Curry (1971) states that the Lebo mudstones provide evidence of the first typical Laramide structural movements in the Powder River Basin. The fact that mudstones were deposited rather than coarse clastics suggests that basin subsidence was the first major movement rather than uplift of adjacent areas.

The Tongue River Member consists of 2000 feet of yellow-weathering sandstone and coal in Montana which thin southward to about 800 feet at Sheridan and 600 feet near Gillette (Mapel, 1958). The Laramie Range, Bighorn Mountains, Black Hills and Casper Arch were uplifted at this time. The most persistent coalbeds in the basin occur in the Tongue River Member of the Fort Union. The largest Fort Union coal seam, the Wyodak-Anderson, commonly ranges from 50-100 feet thick (Glass, 1976).

In the Lake De Smet area near Buffalo, Wyoming, Obennyer (1979) has divided the Fort Union into two members: a lower member of sandstone, silty sandstone, siltstone, and mudstone; and an upper conglomerate member which overlies the lower beds with angular unconformity. The conglanerate member consists of subangular to rounded granule- to boulder-size pieces of Paleozoic sedimentary rocks which crop out to the west.

The contact of the Fort Union Formation of Paleocene age and the overlying Wasatch Formation of Eocene age is still controversial. In sane areas, the contact is a recognizable unconformity, but in other areas the contact is conformable and not easily defined even after detailed study. The Wasatch is 1000-2000 feet thick and is lithologically similar to the Tongue River Member of the Fort Union. It is composed of thin lenticular sandstone, gray claystone, carbonaceous shale and coal, and is drab-yellow to light-gray in outcrop. Rocks of the Wasatch Formation are undifferentiated over most of the basin, except along the west margin, where Obernyer (1979) has subdivided the formation into three members: the Kingsbury Conglomerate Member (O-800 feet thick), an unnamed finer grained sequence (o-2500 feet thick) and the Moncrief Member (o-1400 feet thick). The Kingsbury Conglomerate lies with angular unconformity on the Fort Union and truncates the upper member of the Fort Union Formation. It grades upward and laterally to the east into finer-grained sequences of sandstones, siltstones, mudstones, and occasional thin shales. Overlying the finer sequence is the Moncrief Member, which becomes increasingly coarser-grained upwards, eventually becoming a boulder conglomerate. The exact age and stratigraphic position of the Moncrief Member is still disputed. The area1 distribution of the Wasatch is restricted to an elliptical area in the center of the basin 170 miles long by 60 miles wide (see Figure 3-14). The Wasatch Formation has generally shallow dips of less than $4^{o}$--except along the western margin near the Bighorn Mountains.

The Wasatch is "another prolific coal-bearing formation" (Glass, 1976). It is reported to contain the thickest coalbed in the nation. The Lake De Smet coalbed in the Lake De Smet area is reported to be as much as 220 feet thick, locally.

The relative thickness of the members of the Fort Union and Wasatch Formations is shown in isopach maps (Figures 3-15 and 3-16) and electric-log correlations (Figures 3-17 and 3-18).

Clinker beds covering as much as several square miles have formed from the burning of coal seams in the Tongue River and Wasatch. Clinker consists of fused sandstone and shale formed by the heat of combustion. The burning usually does not affect underlying rocks, but may cause alteration of as much as 50 feet of overlying rocks (Mapel, 1958).

The White River Group of Oligocene age formed after the tectonic movements related to the Laramide Orogeny had stopped. The sedimentary rocks consist of volcanic ash, claystone, and siltstone. The White River Formation was deposited on an erosion surface of considerable relief (Whitcomb, 1965), and the thickness differs from place to place. It is found mainly in the extreme southeastern portion of the Powder River Basin where it is about 560 feet thick. Isolated remnants are also found in Campbell County, in the Bighorn Mountains and in the Black Hills.

The Arikaree Formation of Miocene age consists of tufaceous sandstone and locally derived conglanerates. It is present mainly in the southeast portion of the basin where it is about 600 feet thick (Hodson, Pearl and Druse, 1973).

The White River and Arikaree Formations represent a period of erosion and deposition which nearly buried the Rockies prior to uplift during Late Cenozoic time.

### 3.3.3 Basin Hydrology

#### 3.3.3.1 Surface Water

The Powder River Basin is drained by tributaries of the Missouri River system. The principal drainage is to the N-NE into the Yellowstone River, and includes the Powder, Little Powder, Tongue, Bighorn and Little Bighorn Rivers. Others, including the Bell Fourche and Cheyenne Rivers, drain to the east around the Black Hills Uplift. The North Platte River, bounding the basin on the south, drains to east and has essentially no tributaries draining the Powder River Basin (Figures 3-19). Both perennial and ephemeral streams occur in the region. Bordering the mountain areas, stream flow is mainly from precipitation and snow melt, and is highest during winter snow melt runoff in May and June (Figure 3-20). Streams originating within the basin are mainly ephemeral, flowing only during time of high surface runoff (Figures 3-21 and 3-22). Major stream patterns are dendritic, however, the secondary and tertiary systems are fracture controlled and are dominantly parallel. The secondary tributaries are parallel or subparallel to northeast fracture systems, whereas many of the tertiary stream channels follow the northwest fracture system which is parallel to the basin structural axis. Sparse vegetation and easily erodable Tertiary rocks result in large sediment loads.

The largest use of surface water is for irrigation along stream valleys. Surface water also supplies the municipal needs for the towns of Sheridan, Buffalo, Dayton, Ranchester, and Kaycee (Lageson et al, 1978; Breckenridge, et al, 1974; Hodson, Pearl, and Druse, 1973).

### 3.3.3.2 Ground Water

The principal aquifers in most areas of the Powder River Basin are the Tertiary sandstones of the Fort Union and Wasatch Formations. In the southeast area of the basin, the principal aquifer is the Tertiary Arikaree Formation. In some areas, significant quantities of water occur in alluvial deposits along stream valleys (Figure 3-19).

Pre-Tertiary Aquifers. Pre-Tertiary rocks consist principally of tightly cemented coarse- and fine-grained sandstone, thick beds of shdle and massive beds of porous limestone. Potential aquifers include sandstone of the Lance Formation; the Fox Hills, Fall River and Lakota Sandstones; sandstone in the Sundance Formation; the Tensleep Sandstone; and the Madison and Pahasapa Limestones (Figure 3-23). In the Gillette area, these formations range from 2200 to 10,000 feet in depth. Many of these rocks do not have a large primary permeability, rather, water is heldin fractures, joints and solution cavities.

The Madison Limestone of Mississippian age is deeply buried except in the outcrop area in the Bighorns. It consists of a thick sequence of light yellowish brown to white limestone and dolomite about 200 to 1000 feet thick. Water occurs where the limestones are cavernous and fractured. The major flowing wells near Tensleep, Wyoming, tap the Madison and yield 1100 to 2800 gallons per minute (gpn). The equivalent Pahapsa Limestone to the east yields water to several wells in excess of 500 gpm.

The Amsden Formation overlies the Madison and is mostly cherty dolanite and shale. It is relatively impermeable.

The Tensleep Sandstone of Pennsylvanian age consists of gray to white sandstone with thin beds of dolomite. It is fine- to medium-grained, well-sorted, friable, thick-bedded, with large-scale crossbedding. It is 50 to 500 feet thick and dips steeply toward the basin. The Tensleep Sandstone has sufficient primary permeability to yield moderate to large supplies of water (20-1000 gpm). The Tensleep is considered second to the Madison as a potential irrigation source. Artesian pressure is usually less than in the Madison.

Correlative with the Tensleep Sandstone is the Minnelusa Formation which is composed of sandstone, dolanite and limestone. It is generally more densely cemented, but does yield water from 20 gpm to as much as 1000 gpm in areas where fracturing has increased the permeability.

The Permian and Triassic Chugwater Formation, Goose Egg Formation, Spearfish Formation, Minnekahta Limestone and Opeche Shale consist of shale, gypsum and limestone. Yield from these formations is generally small (10 to 20 gpm).

The Gypsum Spring, Sundance and Morrison Formations consist of gypsum, limestone, and fine-grained sandstone and claystone. Water yields of 10 to 50 gpn are possible in some areas, but generally these formations are not considered good aquifers.

The Cloverly, Fall River and Lakota Formations of Early Cretaceous age consist of shale, siltstone and sandstone. Yields range from 5 to 20 gpm for most wells, but yields of 100 gpm or more are possible from fractured areas.

The Skull Creek Shale is a dark-gray to black shale 200 to 270 feet thick. It is not considered an aquifer.

The Newcastle, or Muddy, Sandstone is a light-gray, fine- to medium-grained sandstone, 20 to 100 feet thick with relatively high permeability. Where saturated it may yield 10 gpm.

The Mowry Shale is 180 to 525 feet of gray to black siliceous shale. It is generally not considered an aquifer, although areas of secondary fracturing may yield as much as 10 gpm.

The Frontier Formation, Cody Shale and Pierre Shale consist of about 4000 feet of gray-black marine shale with lesser amounts of interbedded siltstone and sandstone. Except for the Shannon, Sussex and Groat Sandstone members, these rocks are not considered potential aquifers. Yields Of 20 to 50 gpm are possible from the sandstone beds.

The Fox Hills Sandstone consists of 125 to 700 feet of fine- to medium-grained marine sandstone. It yields as much as 200 gpm water in some areas. It is a principal aquifer in some areas of the northern Powder River Basin in Montana.

The Lance Formation of Upper Cretaceous age is a continental formation of interbedded light-colored sandstone and dark shale, with lenticular deposits of carbonaceous shale. It ranges in thickness from 500 feet to 3000 feet. It is considered a principal aquifer in sane places, although yields are small (less than 20 gpm).

The Tertiary Aquifers. The Tertiary sandstones of the Fort Union and Wasatch Formations are the principal aquifers in most of the Powder River Basin (see Table 3-4). The Fort Union and Wasatch formations are continental deposits, formed in lacustrine, palludal, and flood plain environments. Fort Union time was characterized by large, shallow, inland lakes and marshes. Sedimentary rocks formed at this time include sandstones, shales and coal. During Wasatch time, the Powder River Basin was the site of sluggish, meandering streams and marshes. Channel sands, which persist for several miles, along with beds and lenses of coal were formed at this time (Littleton, 1950).

Water in the Fort Union occurs in thin, lenticular beds of fine-grained gray sandstone, jointed coal, red clinker beds and red shale (Table 3-4). Gas and water are discharged together from some wells that penetrate coal and other carbonaceous material of the Fort Union. Most gas is methane from the coalbeds, and its occurrence is described in more detail in Section 5 of this report. Gas in an aquifer affects the height to which water will rise in a well and may bring the water to the surface due to expansion of the gas and a resulting lifting action (Lowry and Cummings, 1966).

The Fort Union normally yields adequate water for domestic and stock use. The quality of the water differs from well to well, but the dissolved solids content commonly exceeds the limit recommended by the U.S. Public Health Service. The water is usually not used for irrigation because of a potential salinity or sodium hazard.

Water in the Wasatch is contained principally in irregularly bedded lenticular sandstone and in jointed coal and clinker beds. The water is generally under some artesian pressure in the interior of the basin, and occurs under water-table conditions in outcrop areas. The Wasatch yields water for domestic and stock use (lo-500 gpm). The dissolved solids content generally exceeds the limit recommended by the Public Health Service. Water from the Wasatch Formation is not usually used for irrigation because of a potential sodium hazard (Littleton, 1950; Lowry and Cummings, 1966).

The White River Formation consists of claystone and siltstone with some channel deposits of coarse sand and gravel. It ranges to 550 feet thick in the southeastern portion of the basin. Generally, the White River Formation has low permeability. Yields of 5 to 20 gpm are possible in fracture zones, fissures and coarse-grained channel deposits (Whitcomb, 1965; Hodson, et al, 1973).

In Niobrara County, Wyoming, the principal aquifer is the Arikaree Formation of Miocene age. The Arikaree is predaninantly a massive sandstone with beds of siltstone, thin lenticular layers of hard concretionary sandstone, soft volcanic ash, and with a generally persistent coarse basal conglomerate. The Arikaree yields water to domestic, stock, and irrigation wells. Permeability is not uniform, but water quality is good (Whitcomb, 1965).

Water in most formations is under some artesian pressure along the western margin and interior of the basin because of the uplift of the Bighorn Mountains. Precipitation is the main source of recharge in areas of rock outcrops. In the interior of the basin, the near-surface aquifers are recharged by irrigation and the infiltration of surface water.

Alluvial Aquifers. Alluvial, terrace, and flood plain deposits of Quaternary age, fonned in stream valleys, contain significant quantities of water in some areas. The alluvium consists of sand, silt and clay, with a few lenses of fine gravel. It is generally less than 50 feet thick although it may be up to 100 feet thick in some places.

Irrigation is a major source of recharge and is responsible for adequate supplies of ground water in the alluvium in some areas. Water in the alluvium has a low sodium hazard, but a medium to very high salinity hazard. Some wells in alluvium contain excessive amounts of iron as dissolved solids (Littleton, 1950; Lowry and Cummings, 1966; Whitcomb, Cummings and McCullough, 1966).

### 3.3.4 Energy Resources Other Than Coal

In addition to the nation's largest coal resources, the Powder River Basin also contains significant accumulations of oil and gas in Paleozoic and Mesozoic rocks and deposits of uranium in Cenozoic rocks. Powder River Basin is the most active area in the Rocky Mountain area in terms of oil and gas exploration and production. Most drilling by oil companies at the present time has been in Cretaceous rocks, which can range from surface exposures to 12,000 feet or more in depth. In contrast, most exploratory efforts for uranium are restricted to shallow drilling of the younger Tertiary sequences. Since most oil and gas drilling penetrates possible coal-bearing formations, "piggyback" experiments, in cooperation with oil drilling companies might be a feasible method of evaluating methane content in many of the coal beds. Most exploratory drilling for uranium would be too shallow in this regard. U.S. Geological Survey Folio of the Powder River Basin, Map I-847-A (in pocket following Figure 3-2) shows the distribution of various energy resources in the basin.

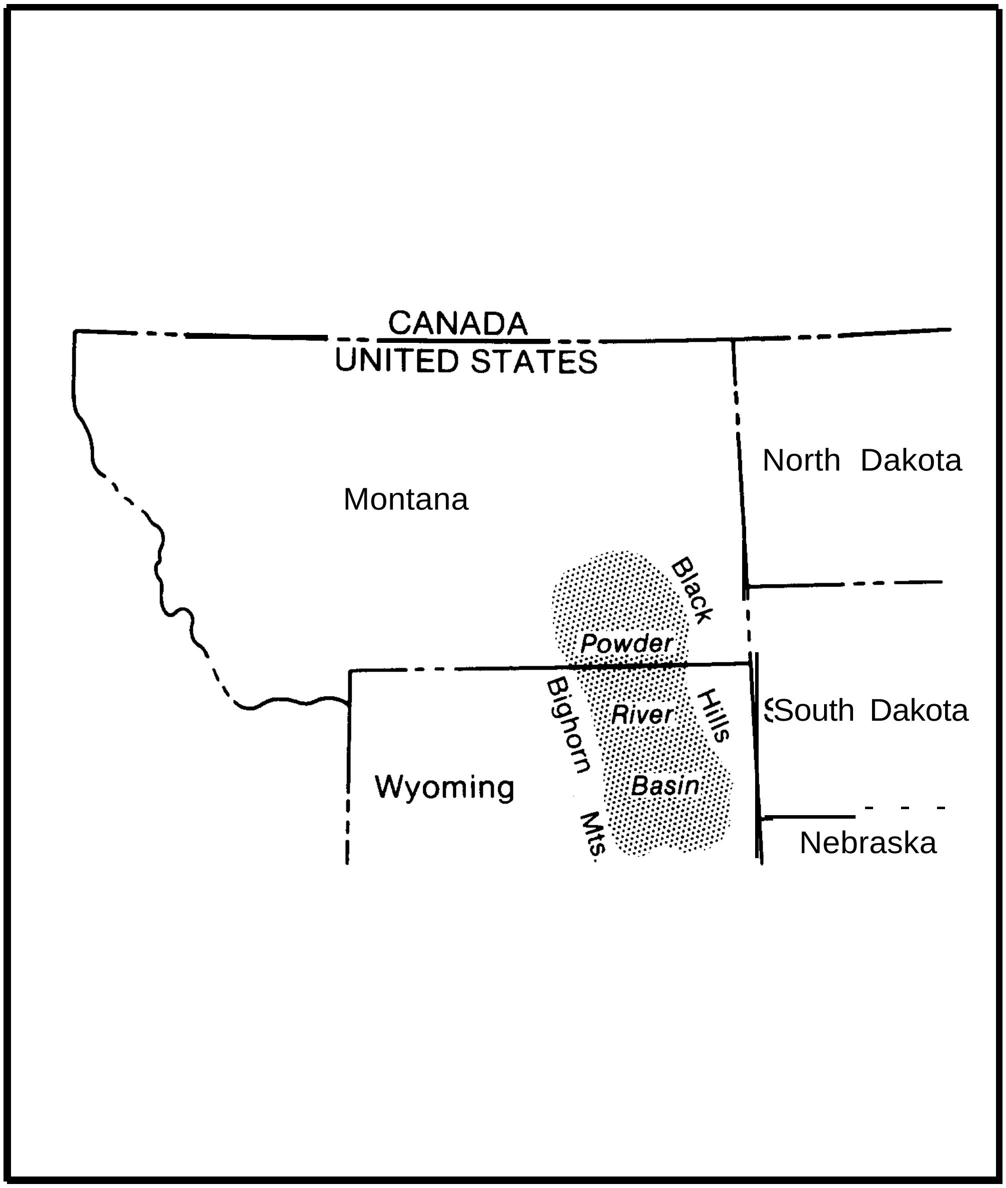



**Figure 3-1.** Index Map Showing Location of the Powder River Basin.

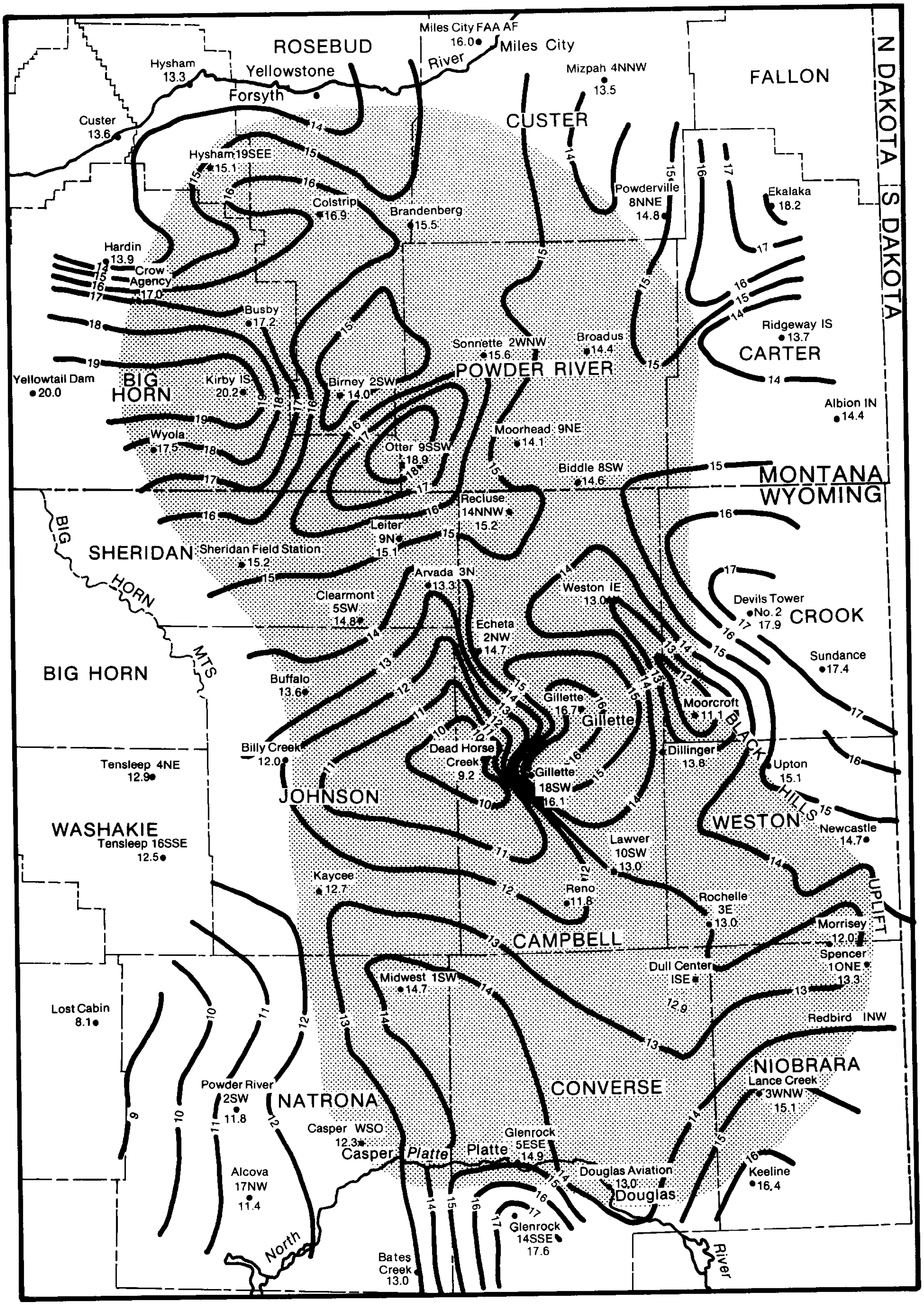



**Figure 3-3** Mean Annual Precipitation in Inches (Toy and Munson, 1978)

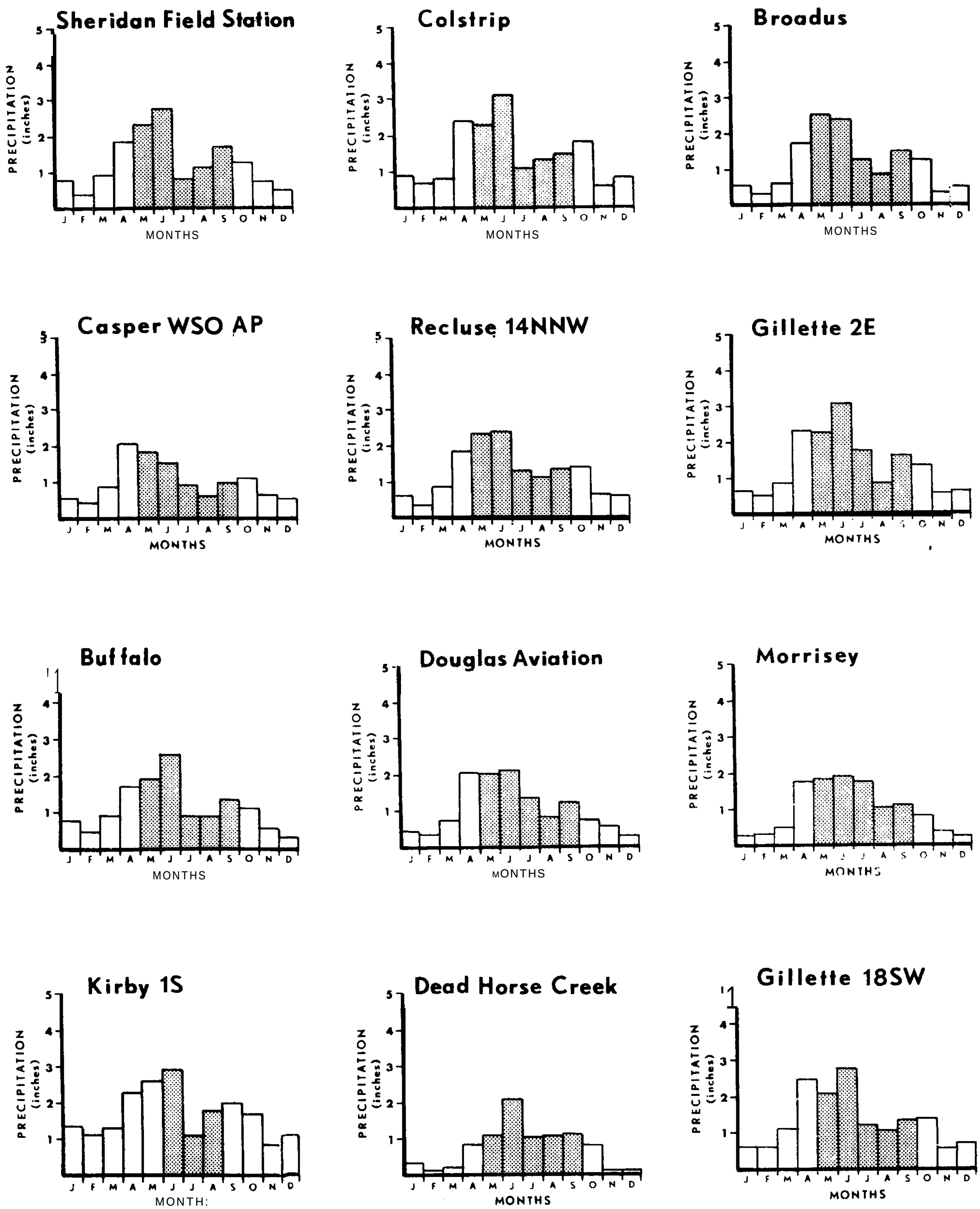



**Figure 3-4** Monthly Precipitation in Inches for Twelve Stations in the Powder River Basin Area (From Toy and Munson, 1978).

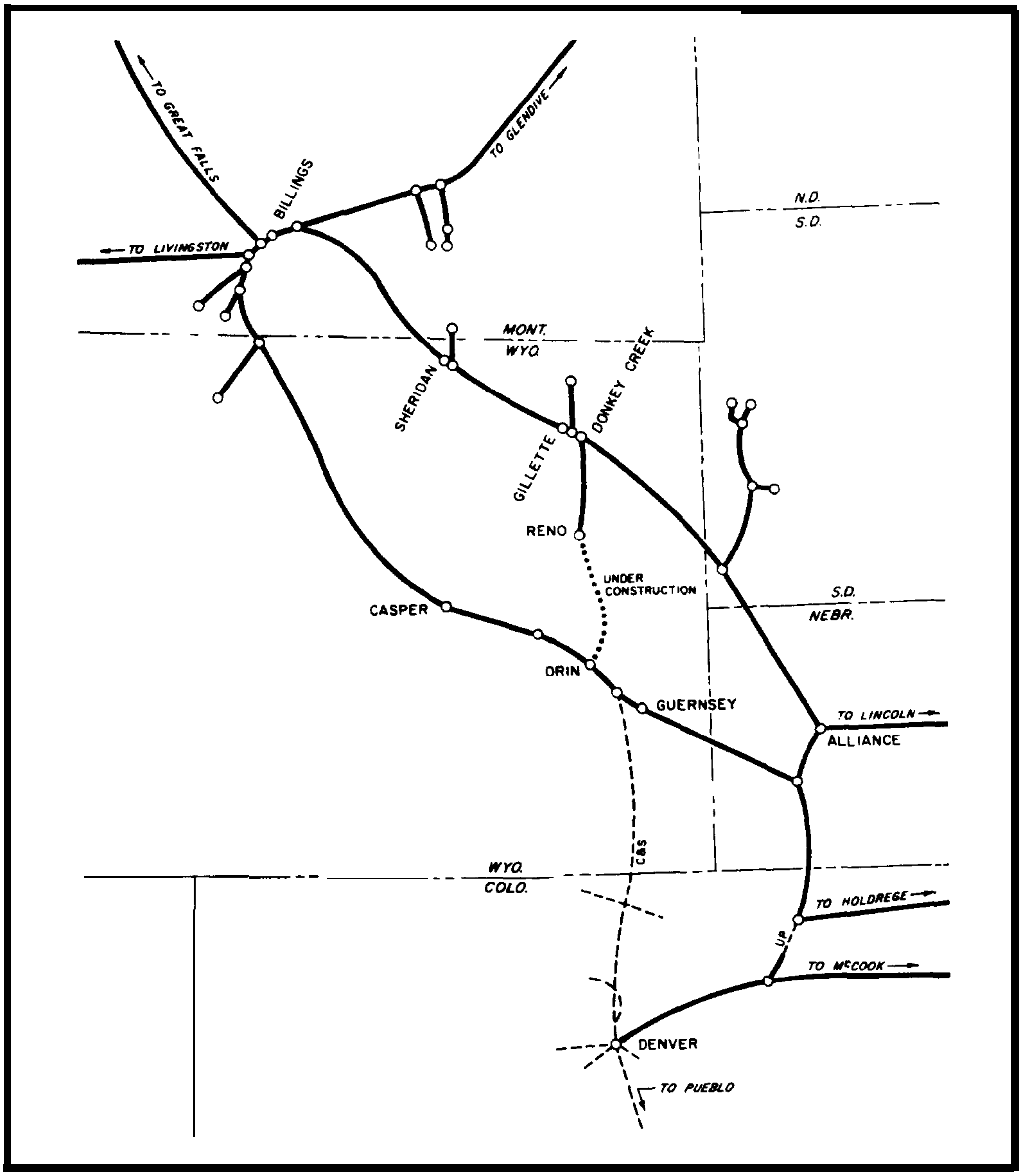



**Figure** 3-5 Rail Lines in the Powder River Basin Area (Skillings' Mining Review, 1979).

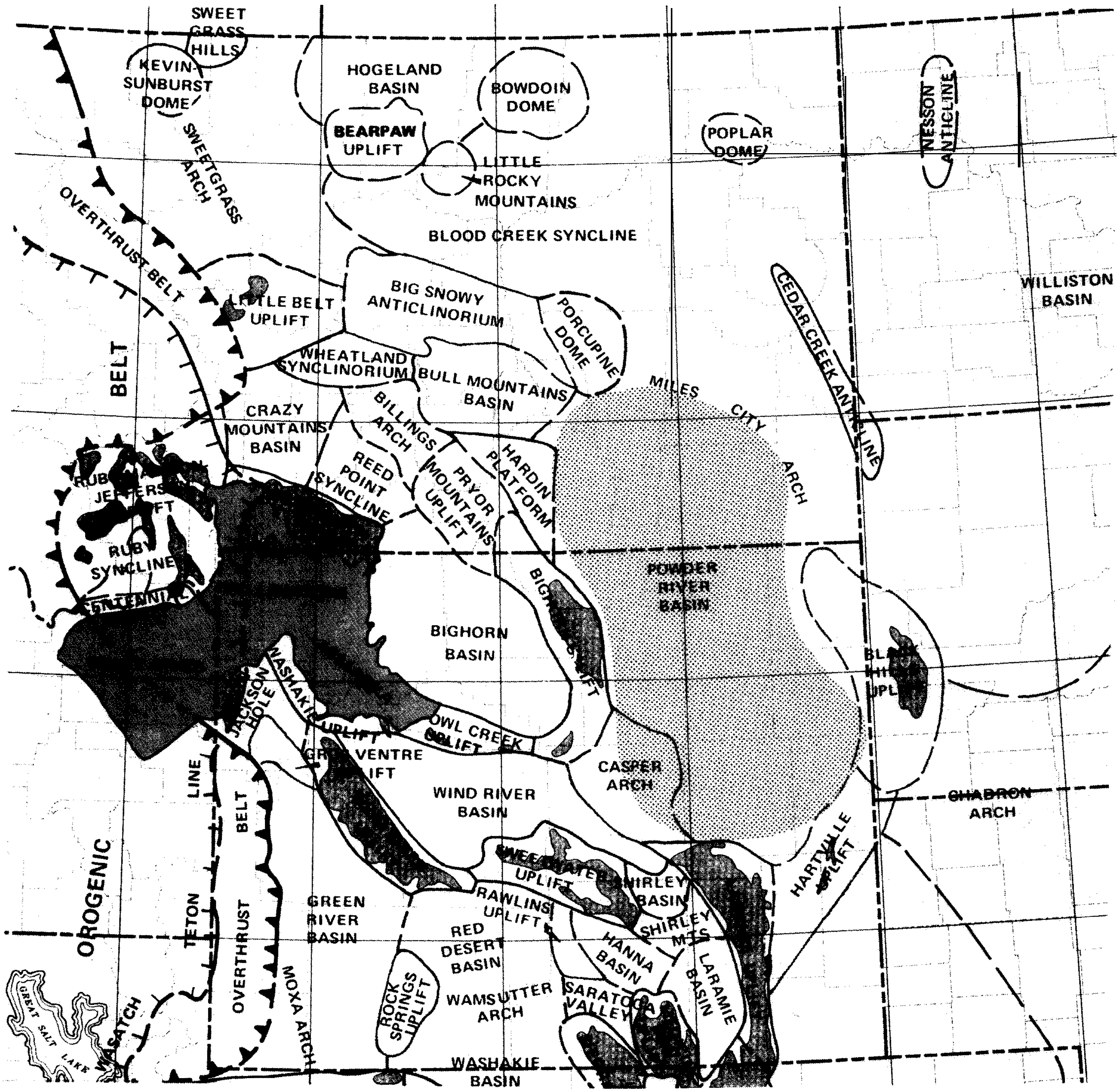



**Figure 3-6** Major Tectonic Elements Associated with Development of Powder River Basin. (Modified from Grose, 1972).

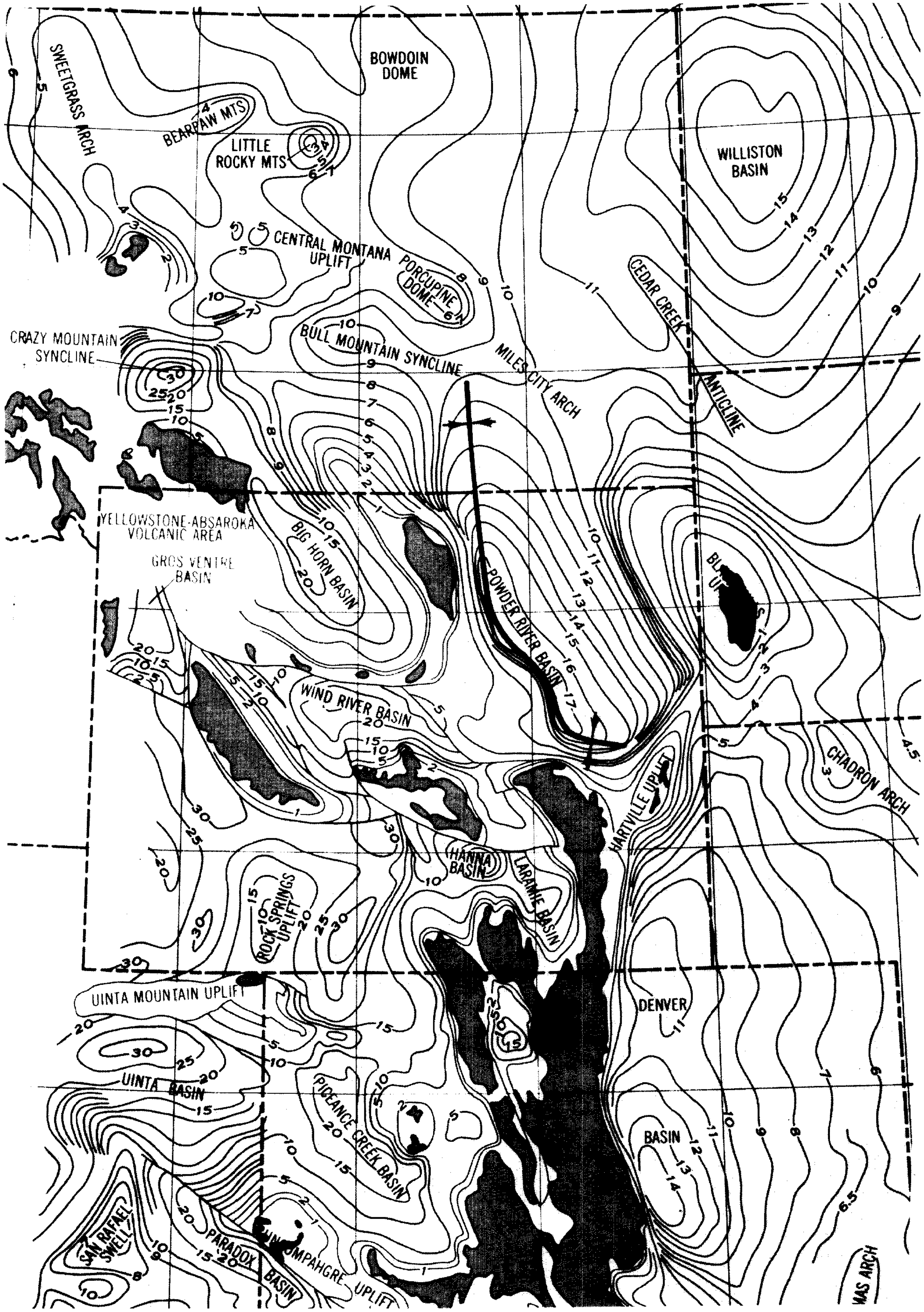



**Figure 3-7** Depth to the Top of the Precambrian Basement Showing Thickness in Thousands of Fee o Sedimentary Rock Sequence in Powder River Basin and Associated Structurally Negative Areas (Modified from Kent, 1972).

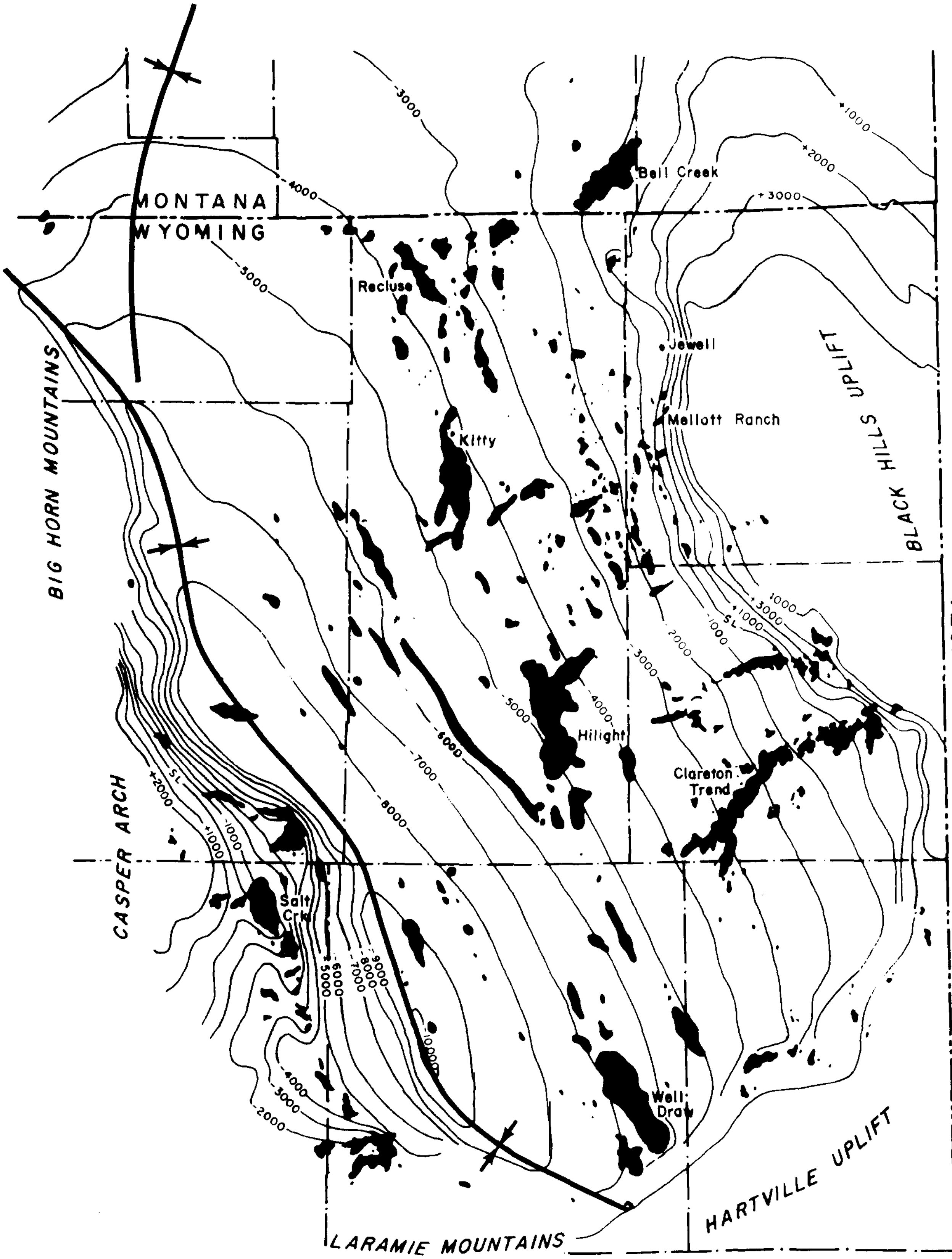



**Figure 3-10** Structural Map of Powder River Basin, Contours on Top of the Dakota Formation. Shown Also are Oil Fields of the Basin and Their Relationship to Basin Structural Grain (Modified from Arro, 1976).

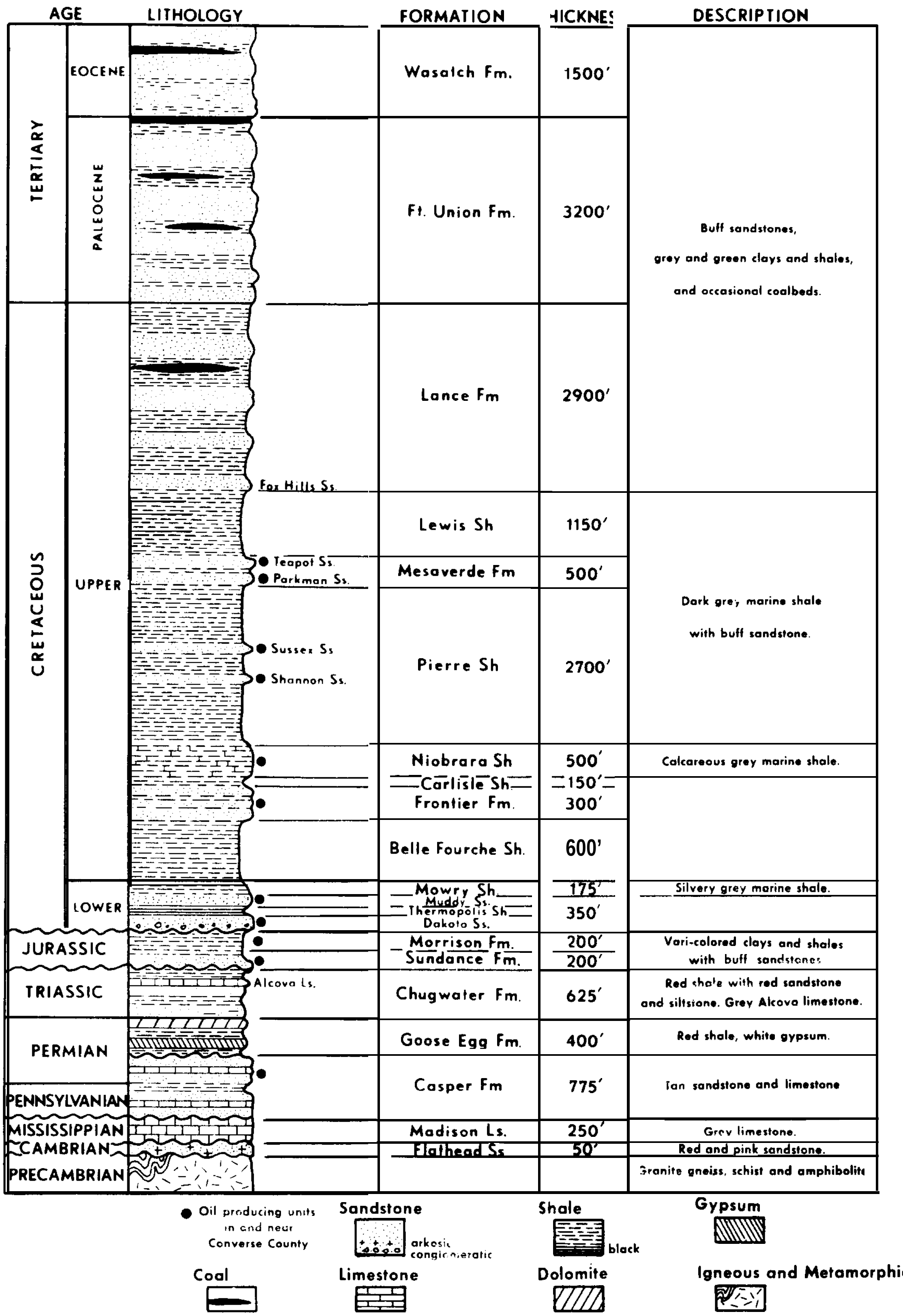



**Figure 3-13** Representative Stratigraphic Column Showing Relationships Between Major Coal-Bearing Formations and Oil-Bearing Sandstones, Converse County, Southwestern Powder River Basin (Lane, Root, Glass, 1972).

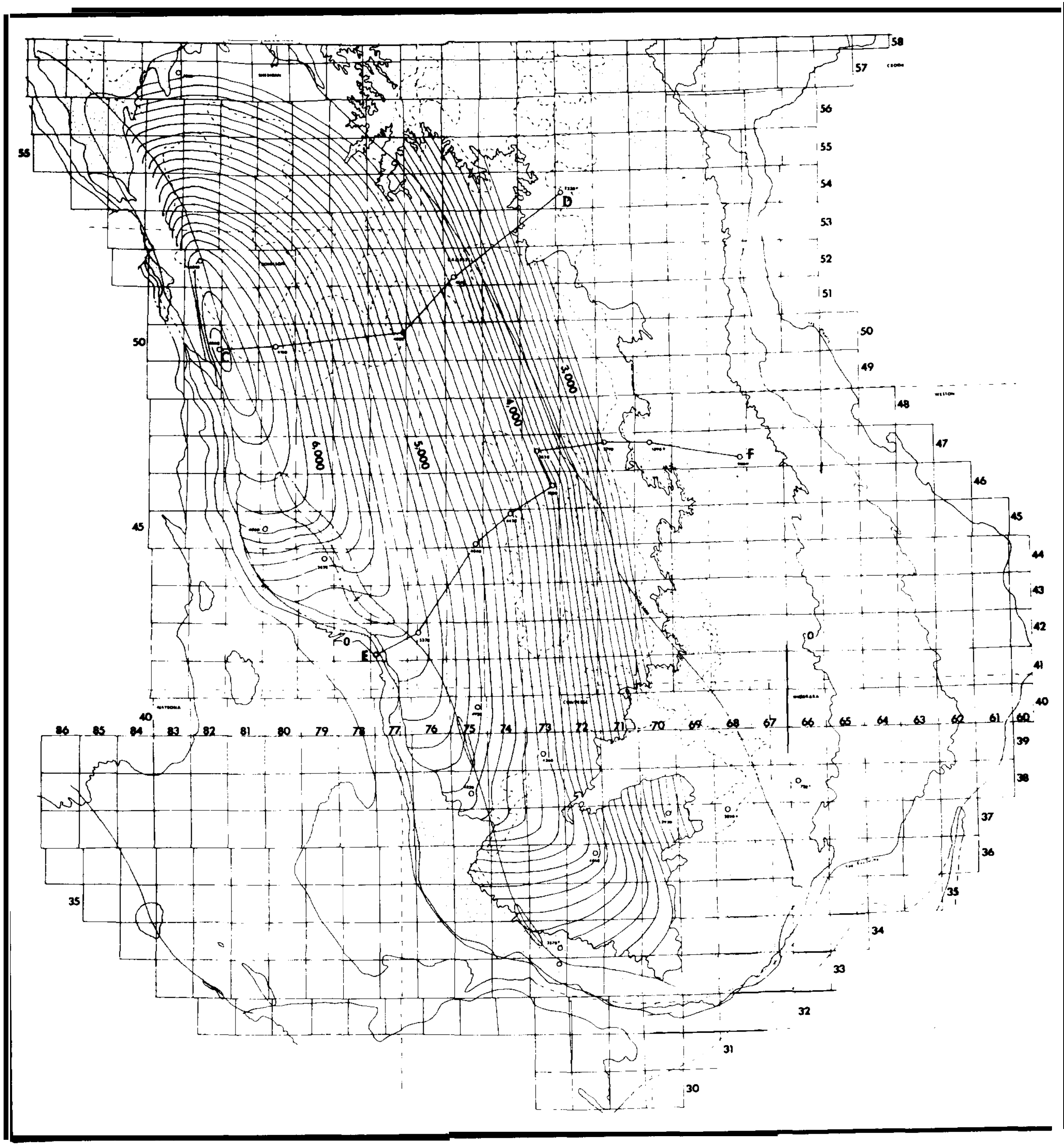



**Figure 3-15** Isopach Map of the Fort Union and Wasatch Formations, Powder River Basin. Dashed Lines Indicate Areas of Thick Coal Outcrops (From Curry, 1971).

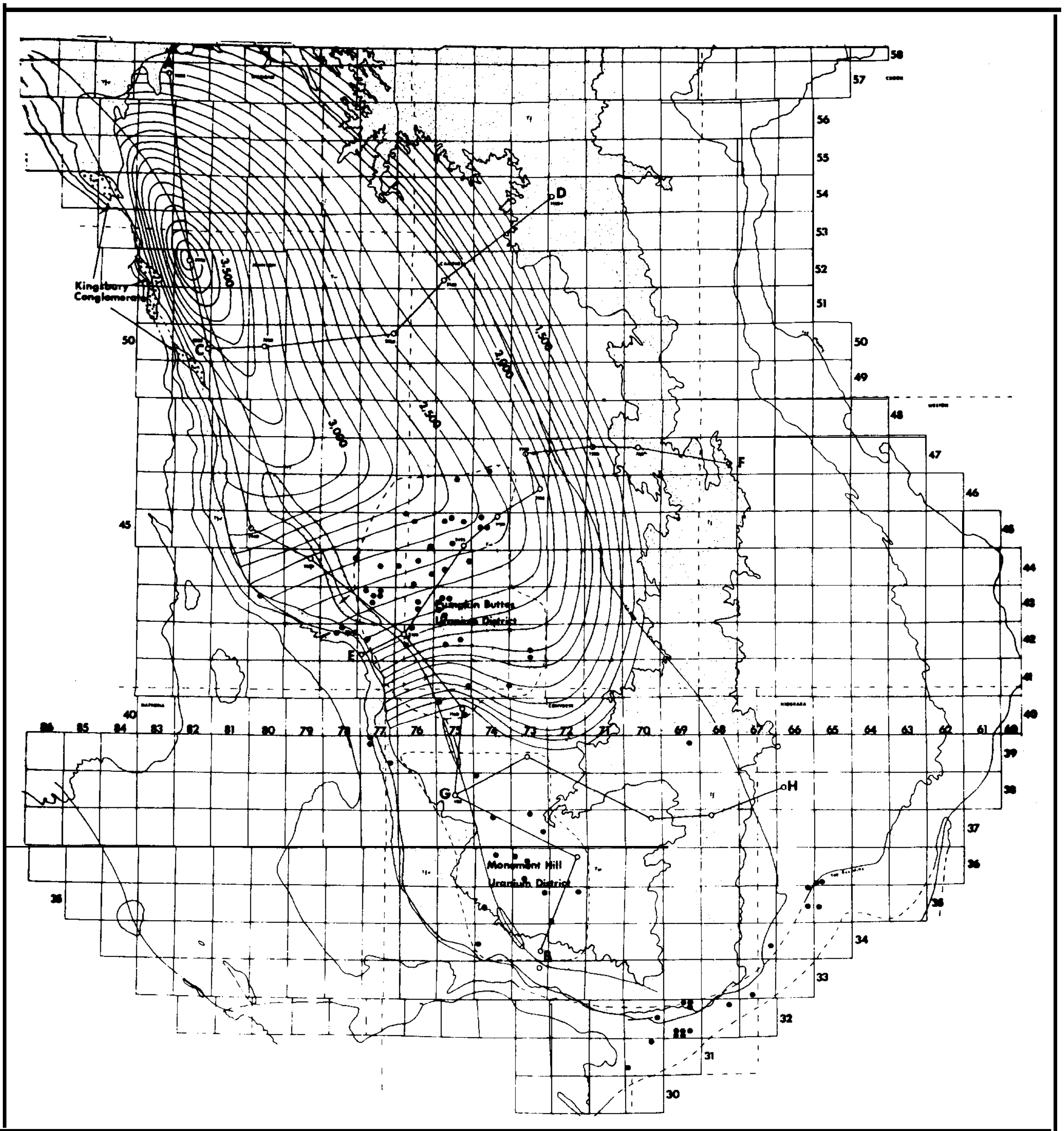



**Figure 3-16** Isopach Map of Tongue River Member and Wasatch Formation, Powder River Basin (From Curry, 1971).

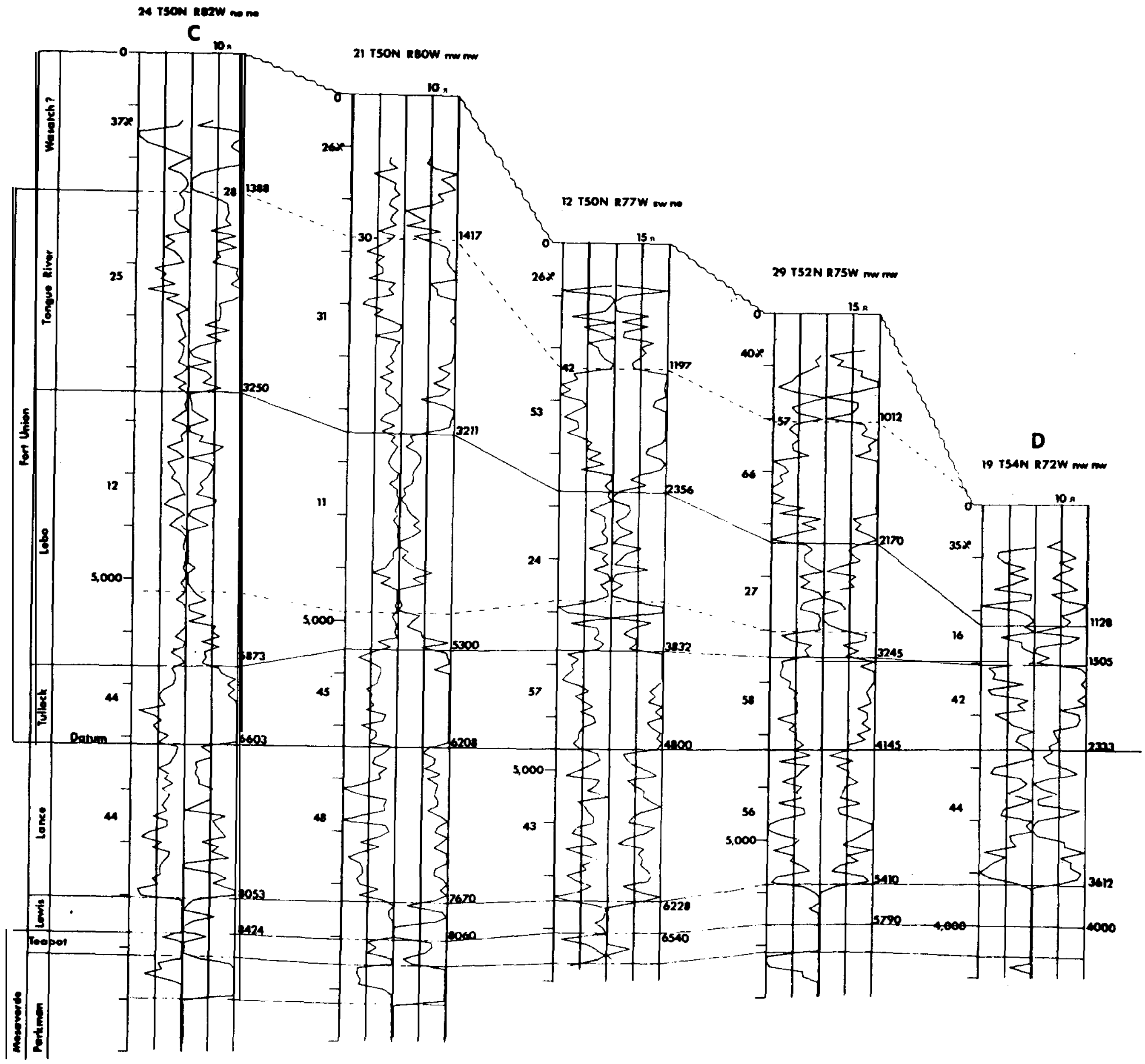



Figure 3-17 Cross-Section C-D of Figure 3-16 Showing Electric Log Correlations (From Curry, 1971).

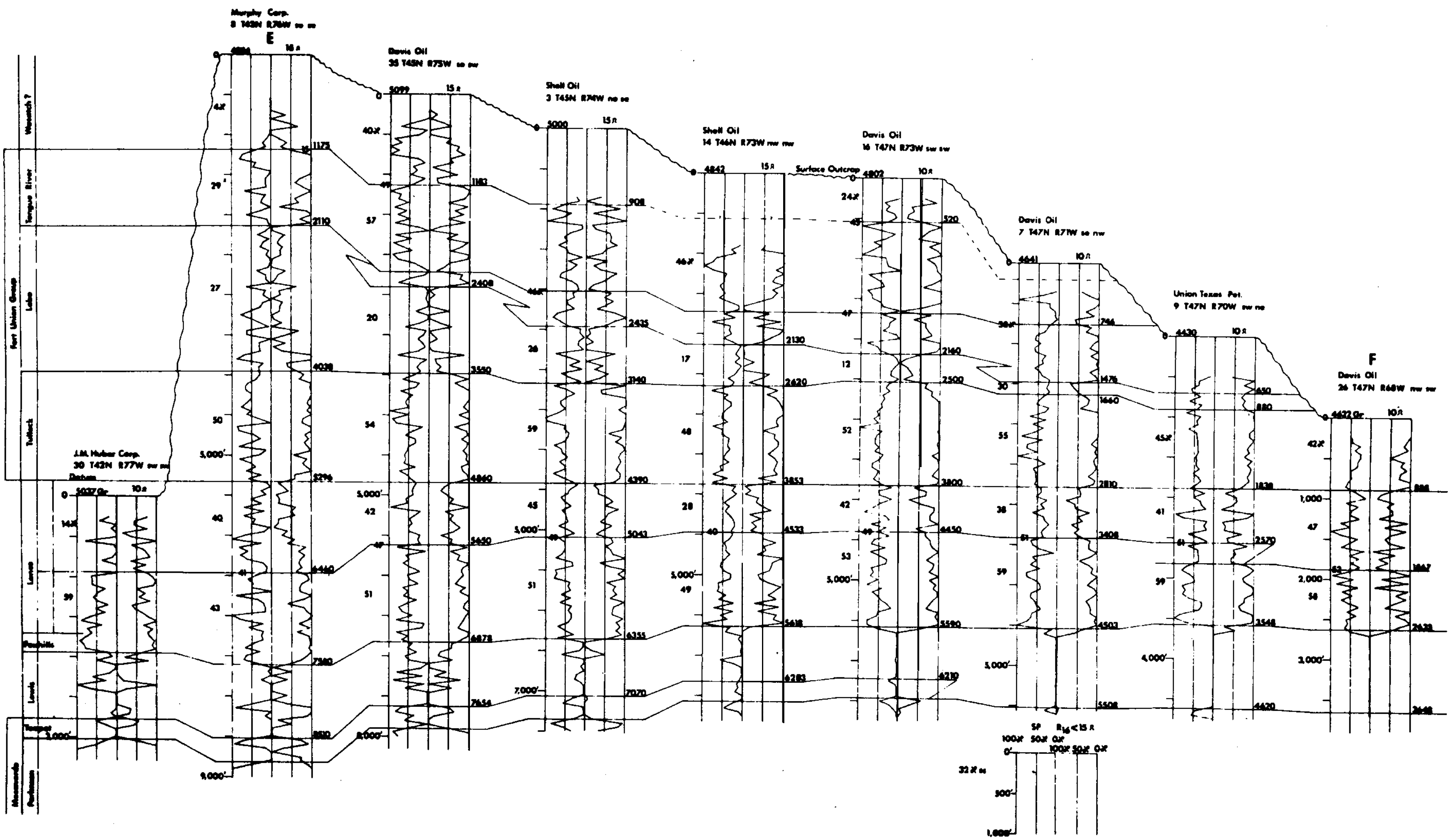


**Figure 3-18** Cross-Section E-F of Figure 3-16 Showing Electric Log Correlations (From Curry, 1971).

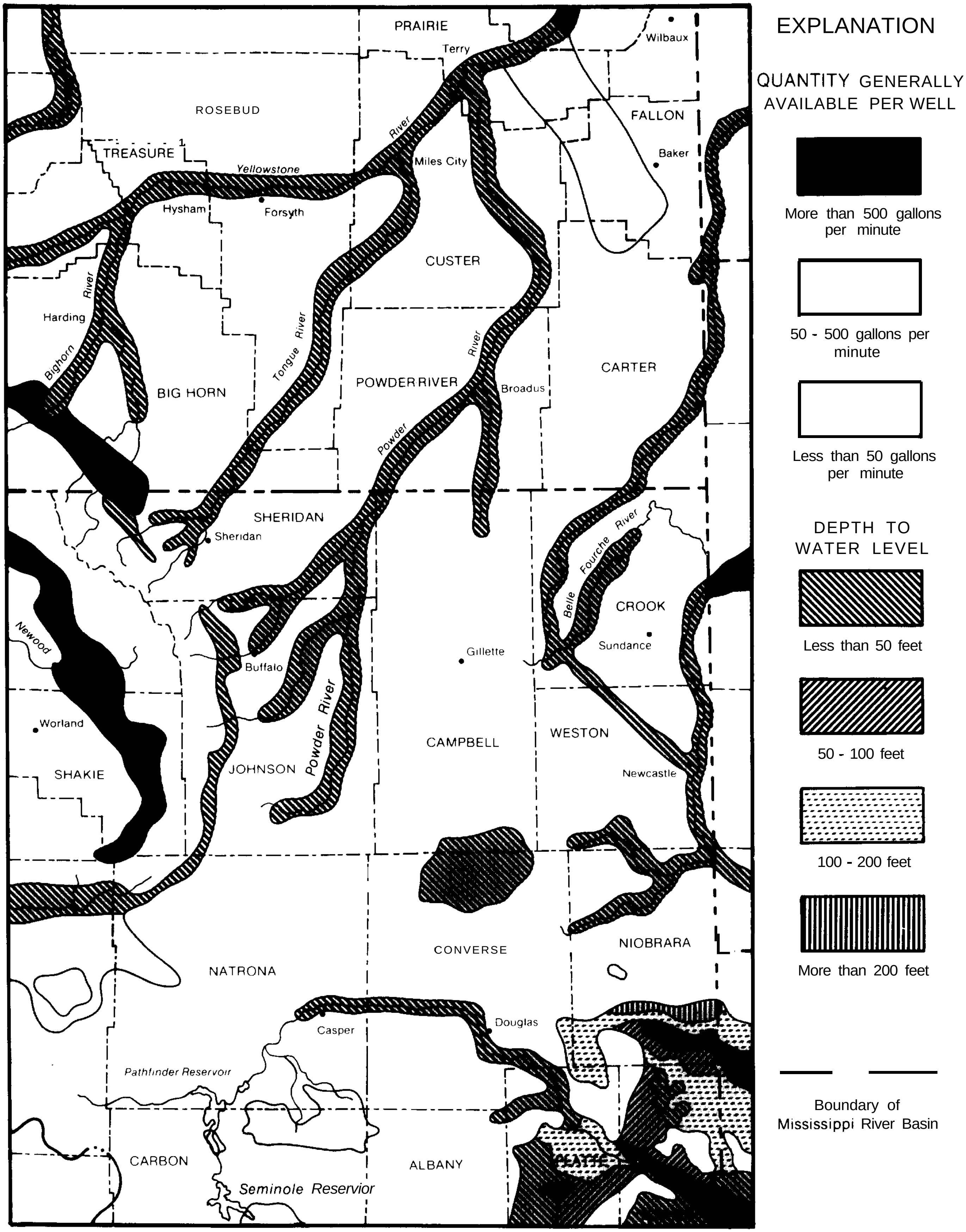
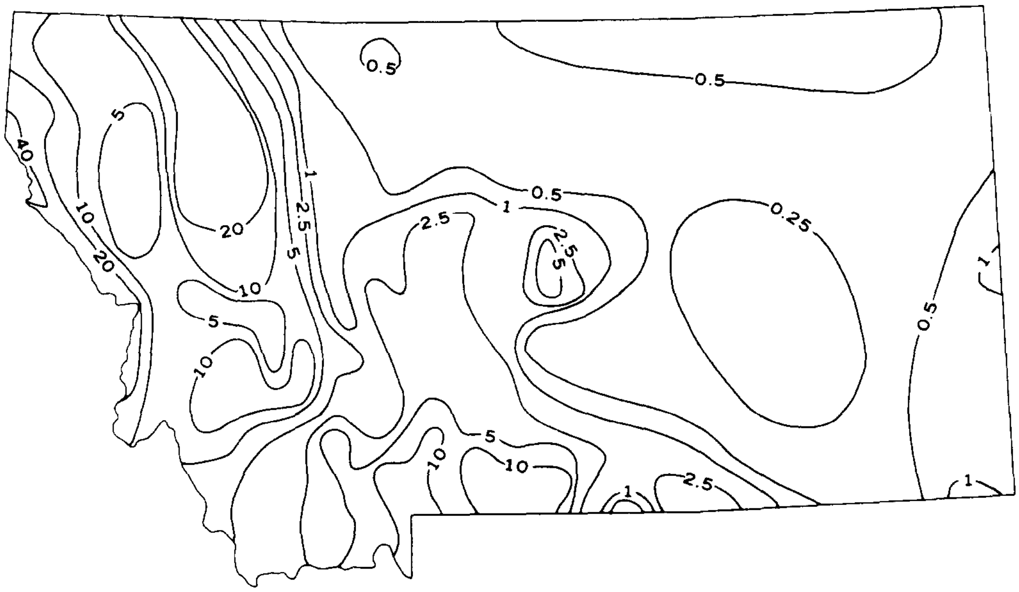


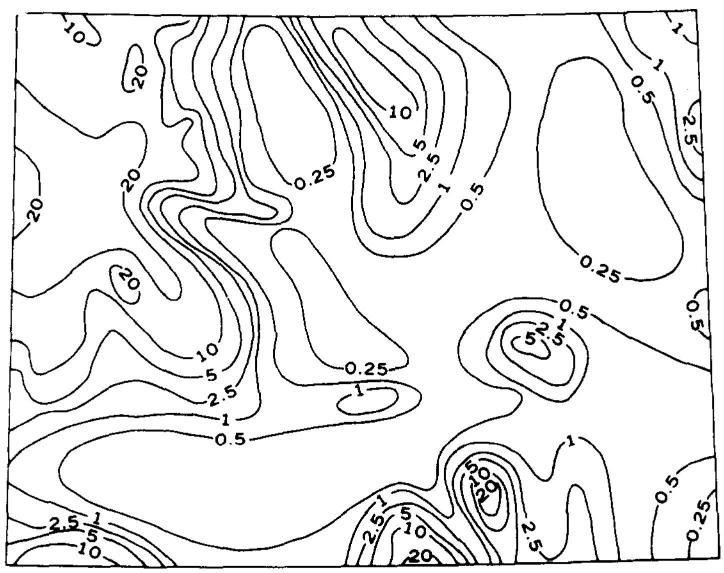

**Figure 3-19** General Availability of Groundwater in the Powder River Basin Area of the Missouri River Drainage Basin (from LaRocque, 1966).

a.) MONTANA




AVERAGE ANNUAL RUNOFF, IN INCHES

b.) WYOMING




AVERAGE ANNUAL RUNOFF, IN INCHES

**Figure 3-20** Average Runoff in Inches, from U.S. Geological Survey, 1976 (a) Montana (b) Wyoming

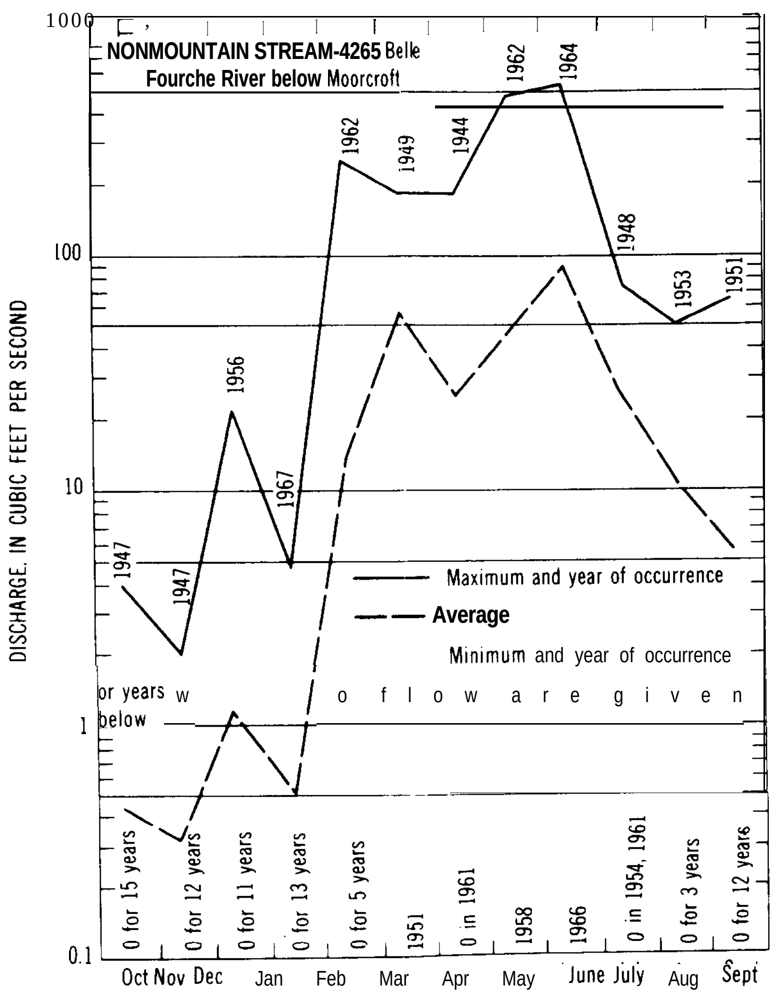



**Figure 3-21** Discharge Hydrograph of Monthly Flows Showing Average, Maximum and Years of No Flow for Belle Fourche River (Hodson, Pearl and Druse, 1973).

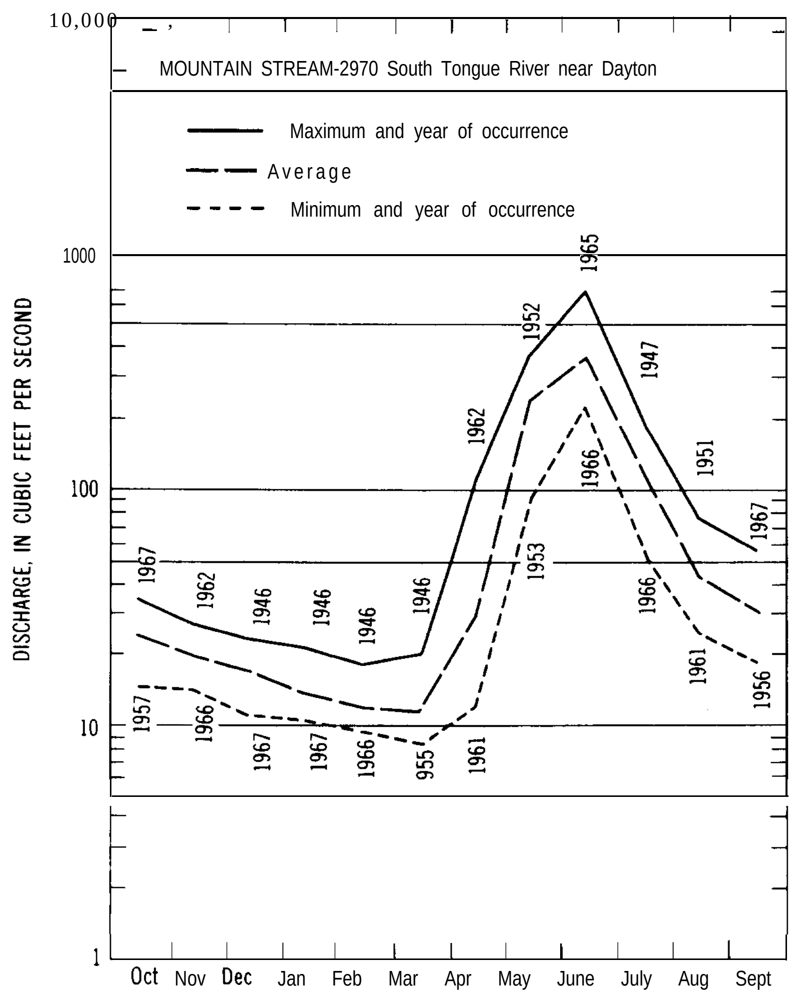



**Figure 3-22** Discharge Hydrograph of Monthly Flows Showing Mean, Minimum and Maximum for South Tongue River (Hodson, Pearl and Druse, 1973).

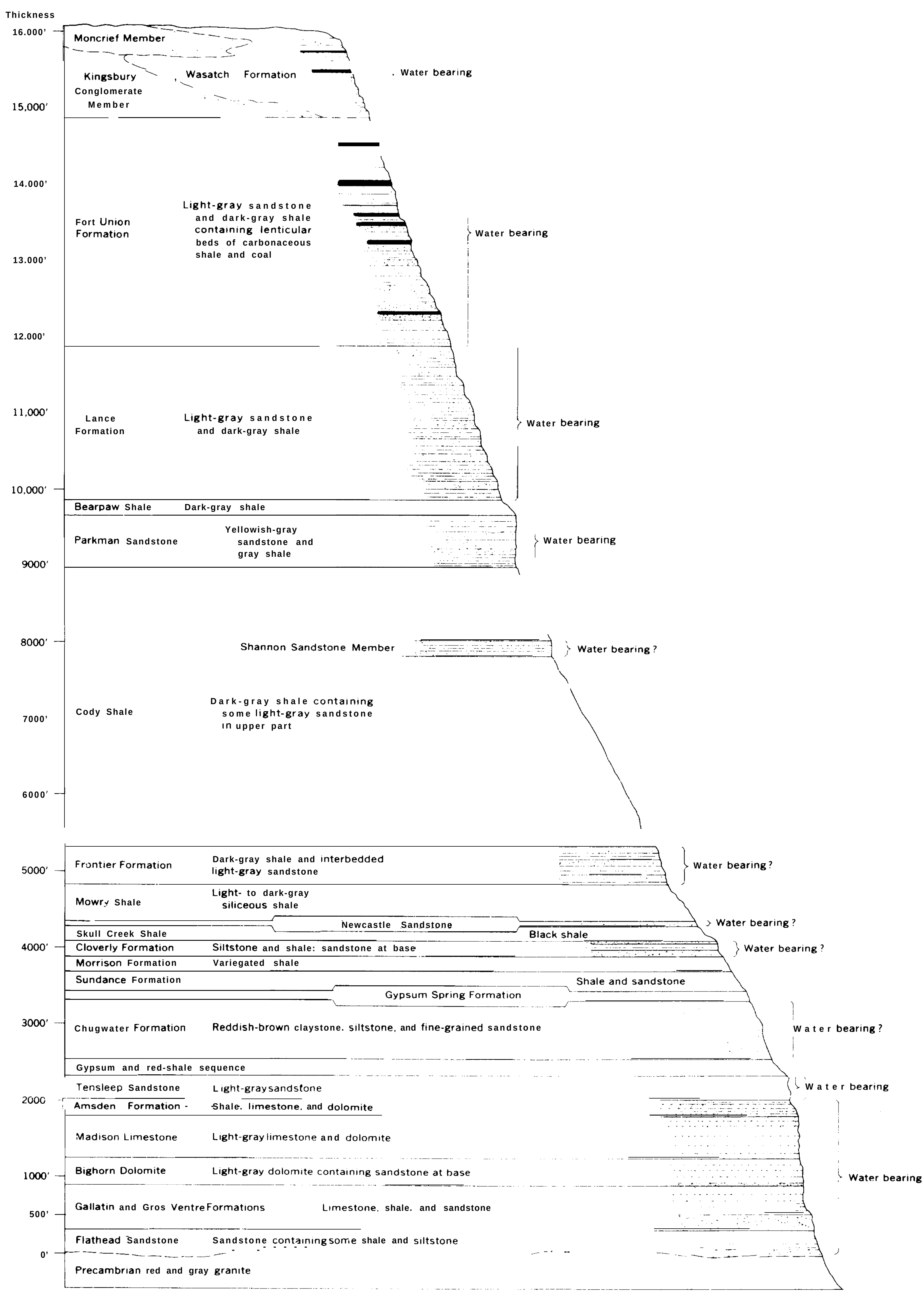



**Figure** 3-23 Generalized Columnar Section Showing Rocks of Northern and Central Johnson County, Wyoming (From Whitcomb, Cummings and McCullough, 1966).

**Table 3-1** Normals, Means, and Extremes for Temperature, Precipitation, Relative Humidity, Wind, and Sunshine; Miles City, Montana; Casper and Sheridan, Wyoming. (National Oceanic and Atmospheric Administration, 1977; 1978.)

## NORMALS, MEANS, AND EXTREMES

**MILES CITY, MT** MUNICIPAL AIRPORT MOUNTAIN 46° 26' N 105° 52' W 2629 FT. 1976

| Month | Temperatures °F: Normal: Daily maximum | Daily minimum | Monthly | Extremes: Record highest | Year | Record lowest | Year | Normal Degree days Base 65 °F: Heating | Cooling | Precipitation in inches: Water equivalent: Normal | Maximum monthly | Year | Minimum monthly | Year | Maximum in 24 hrs. $ | Year | Snow, Ice pellets: Maximum monthly | Year | Maximum in 24 hrs. $ | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | | | | 39 | | 39 | | | | | 39 | | 39 | | 27 | | 36 | | 17 | |
| J | 26.1 | 4.7 | 15.4 | 62 | 1953 | -37 | 1969 | 1538 | 0 | 0.49 | 1.78 | 1971 | 0.08 | 1961 | 0.42 | 1944 | 17.2 | 1971 | 7.5 | 1964 |
| F | 32.8 | 10.4 | 21.6 | 66 | 1961 | -37 | 1939 | 1215 | 0 | 0.51 | 1.30 | 1959 | 0.08 | 1954 | 0.77 | 1952 | 19.0 | 1949 | 6.5 | 1952 |
| M | 41.6 | 18.7 | 30.2 | 83 | 1943 | -27 | 1947 | 1079 | 0 | 0.65 | 1.83 | 1950 | 0.07 | 1959 | 0.61 | 1944 | 17.8 | 1967 | 5.0 | 1957 |
| A | 57.8 | 32.7 | 45.3 | 91 | 1952 | 7 | 1954 | 591 | 0 | 1.26 | 4.22 | 1973 | 0.10 | 1952 | 1.36 | 1947 | 16.6 | 1967 | 10.5 | 1947 |
| M | 68.9 | 43.6 | 56.3 | 99 | 1964 | 15 | 1954 | 288 | 19 | 2.06 | 5.33 | 1955 | 0.24 | 1958 | 2.39 | 1955 | 8.6 | 1967 | 2.0 | 1953 |
| J | 77.4 | 52.3 | 64.9 | 104 | 1961 | 32 | 1951 | 117 | 114 | 3.32 | 9.78 | 1944 | 0.84 | 1961 | 2.71 | 1964 | 2.0 | 1950 | 2.0 | 1950 |
| J | 88.9 | 59.8 | 74.4 | 109 | 1960 | 41 | 1945 | 9 | 301 | 1.55 | 4.58 | 1948 | 0.10 | 1971 | 2.02 | 1962 | 0.0 | | 0.0 | |
| A | 87.2 | 57.7 | 72.5 | 110 | 1949 | 35 | 1966 | 16 | 248 | 1.20 | 4.00 | 1951 | T | 1967 | 1.65 | 1943 | 0.0 | | 0.0 | |
| S | 73.5 | 46.2 | 59.9 | 105 | 1950 | 20 | 1942 | 217 | 64 | 1.19 | 4.67 | 1941 | T | 1960 | 2.67 | 1941 | 7.1 | 1972 | 0.7 | 1950 |
| O | 62.1 | 35.5 | 48.8 | 93 | 1963 | 9 | 1972 | 508 | 6 | 0.71 | 6.31 | 1971 | T | 1965 | 1.38 | 1953 | 12.6 | 1949 | 3.8 | 1946 |
| N | 43.1 | 21.7 | 32.4 | 75 | 1965 | -23 | 1955 | 978 | 0 | 0.51 | 1.33 | 1964 | 0.02 | 1953 | 1.18 | 1957 | 14.6 | 1955 | 8.0 | 1964 |
| D | 32.2 | 11.7 | 22.0 | 69 | 1939 | -31 | 1951 | 1333 | 0 | 0.48 | 1.78 | 1968 | 0.02 | 1957 | 0.50 | 1941 | 18.0 | 1968 | 7.0 | 1958 |
| YR | 57.6 | 32.9 | 45.3 | 110 | AUG 1949 | -37 | JAN 1969 | 7889 | 752 | 13.93 | 9.78 | JUN 1944 | T | AUG 1967 | 2.71 | JUN 1964 | 19.0 | FEB 1949 | 10.5 | APR 1947 |

| Month | Relative humidity pct.: Hour (Local time) | Hour | Hour | Hour | Wind: Mean speed m.p.h. | Prevailing direction | Fastest mile: Speed m.p.h. | Direction | Year | Pct. of possible sunshine | ∅ Mean sky cover, tenths, sunrise to sunset | Mean number of days: ∅ Sunrise to sunset: Clear | Partly cloudy | Cloudy | Precipitation .01 inch or more | Snow, Ice pellets 1.0 inch or more | Thunderstorms | Heavy fog, visibility ¼ mile or less | Temperatures °F: Max: (b) 90° and above | 32° and below | Min: 32° and below | 0° and below | Average station pressure mb. Elev 2634 feet m.s.l. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | 16 | 16 | 16 | 16 | 27 | 14 | | | | | 13 | 18 | 18 | 18 | 39 | 27 | 26 | 24 | 32 | 32 | 32 | 32 | 4 |
| J | 74 | 70 | 70 | 74 | 9.6 | NW | | | | | 6.8 | 6 | 8 | 17 | 8 | 2 | 0 | 1 | 0 | 18 | 30 | 12 | 921.2 |
| F | 80 | 70 | 68 | 77 | 9.7 | NW | | | | | 7.0 | 5 | 8 | 15 | 7 | 2 | 0 | 2 | 0 | 13 | 28 | 7 | 921.2 |
| M | 79 | 62 | 55 | 74 | 10.9 | NW | | | | | 6.9 | 5 | 8 | 18 | 8 | 2 | * | 1 | 0 | 8 | 27 | 3 | 917.7 |
| A | 79 | 54 | 48 | 70 | 11.8 | NW | | | | | 6.8 | 5 | 8 | 17 | 9 | 2 | 1 | 1 | * | 1 | 15 | 0 | 919.7 |
| M | 78 | 49 | 44 | 67 | 11.1 | SE | | | | | 6.5 | 6 | 10 | 15 | 11 | * | 4 | 1 | 1 | * | 2 | 0 | 919.8 |
| J | 78 | 48 | 41 | 65 | 10.4 | SE | | | | | 5.5 | 8 | 10 | 12 | 12 | * | 8 | * | 4 | 0 | * | 0 | 918.6 |
| J | 68 | 38 | 31 | 54 | 9.7 | SE | | | | | 4.0 | 15 | 12 | 4 | 8 | 0 | 7 | * | 16 | 0 | 0 | 0 | 921.4 |
| A | 64 | 38 | 28 | 49 | 9.7 | SE | | | | | 4.0 | 15 | 11 | 5 | 6 | 0 | 6 | * | 14 | 0 | 0 | 0 | 921.3 |
| S | 73 | 47 | 39 | 60 | 9.9 | NW | | | | | 5.1 | 10 | 10 | 10 | 7 | * | 2 | 1 | 3 | 0 | 2 | 0 | 924.2 |
| O | 74 | 51 | 47 | 65 | 9.8 | SSE | | | | | 5.4 | 12 | 8 | 11 | 6 | * | * | 1 | * | * | 11 | 0 | 922.6 |
| N | 79 | 65 | 63 | 74 | 9.8 | SSE | | | | | 6.6 | 7 | 7 | 16 | 6 | 2 | * | 1 | 0 | 6 | 26 | 2 | 922.8 |
| D | 77 | 71 | 71 | 77 | 9.7 | SSE | | | | | 6.5 | 7 | 8 | 16 | 7 | 2 | * | 2 | 0 | 15 | 30 | 7 | 921.3 |
| YR | 75 | 55 | 51 | 67 | 10.2 | SE | | | | | 5.9 | 101 | 108 | 156 | 94 | 13 | 28 | 10 | 38 | 60 | 172 | 31 | 921.0 |

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

## Table 3-1 (Continued)

### CASPER, WY — NATRONA COUNTY INTL AIRPORT — MOUNTAIN — 42° 55' N — 106° 28' W — 5338 FT — 1977

| Month | Temperatures °F Normal Daily maximum | Normal Daily minimum | Normal Monthly | Extremes Record highest | Year | Record lowest | Year | Normal Degree days Base 65 °F Heating | Cooling | Precipitation in inches Water equivalent Normal | Maximum monthly | Year | Minimum monthly | Year | Maximum in 24 hrs. | Year | Snow, Ice pellets Maximum monthly | Year | Maximum in 24 hrs. | Year | Relative humidity pct. Hour 05 (Local time) | Hour 11 | Hour 17 | Hour 23 | Wind Mean speed m.p.h. | Prevailing direction | Fastest mile Speed m.p.h. | Direction | Year | Pct. of possible sunshine | Mean sky cover, tenths, sunrise to sunset | Mean number of days Sunrise to sunset Clear | Partly cloudy | Cloudy | Precipitation .01 inch or more | Snow, Ice pellets 1.0 inch or more | Thunderstorms | Heavy fog, visibility ¼ mile or less | Temperatures °F Max. (b) 90° and above | Max. 32° and below | Min. 32° and below | Min. 0° and below | Average station pressure mb. Elev. 5290 feet m.s.l. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | | | | 27 | | 27 | | | | | 27 | | 27 | | 27 | | 27 | | 27 | | 13 | 13 | 13 | 13 | 27 | 13 | 24 | 24 | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 13 | 13 | 13 | 13 | 5 |
| J | 33.6 | 12.7 | 23.2 | 60 | 1971 | -40 | 1972 | 1296 | 0 | 0.50 | 0.99 | 1972 | T | 1952 | 0.53 | 1972 | 19.2 | 1972 | 9.7 | 1972 | 68 | 59 | 61 | 68 | 16.8 | SW | 58 | 20 | 1954 | | 6.7 | 6 | 8 | 17 | 7 | 3 | 0 | 1 | 0 | 13 | 29 | 7 | 835.3 |
| F | 37.7 | 15.9 | 26.8 | 65 | 1962 | -19 | 1960 | 1070 | 0 | 0.50 | 1.01 | 1955 | 0.15 | 1957 | 0.42 | 1977 | 23.8 | 1952 | 10.4 | 1952 | 69 | 57 | 55 | 68 | 15.3 | SW | 58 | 23 | 1957 | | 6.5 | 6 | 8 | 14 | 8 | 3 | * | 1 | 0 | 8 | 27 | 3 | 836.1 |
| M | 42.6 | 19.4 | 31.0 | 73 | 1966 | -21 | 1965 | 1054 | 0 | 0.91 | 2.43 | 1954 | 0.25 | 1953 | 1.00 | 1958 | 36.2 | 1975 | 14.6 | 1954 | 71 | 53 | 48 | 69 | 14.3 | SW | 81 | 25 | 1956 | | 6.7 | 6 | 9 | 16 | 9 | 4 | * | 1 | 0 | 6 | 27 | 2 | 831.5 |
| A | 55.5 | 29.9 | 42.7 | 81 | 1962 | -4 | 1966 | 669 | 0 | 1.45 | 3.92 | 1974 | 0.20 | 1952 | 3.00 | 1974 | 56.3 | 1973 | 16.5 | 1973 | 76 | 50 | 44 | 70 | 12.9 | WSW | 54 | 25 | 1967 | | 6.8 | 6 | 9 | 15 | 10 | 4 | 1 | 2 | 0 | 1 | 20 | * | 834.7 |
| M | 66.1 | 39.3 | 52.7 | 91 | 1969 | 16 | 1953 | 388 | 6 | 1.94 | 5.59 | 1971 | 0.30 | 1966 | 2.07 | 1952 | 23.9 | 1950 | 14.1 | 1950 | 77 | 43 | 39 | 68 | 11.8 | WSW | 58 | 32 | 1959 | | 6.6 | 6 | 11 | 14 | 10 | 1 | 6 | 1 | * | * | 8 | 0 | 835.2 |
| J | 76.3 | 47.4 | 61.9 | 101 | 1970 | 28 | 1969 | 147 | 54 | 1.44 | 3.75 | 1967 | 0.03 | 1956 | 1.67 | 1969 | 3.0 | 1969 | 3.0 | 1969 | 77 | 40 | 34 | 64 | 11.1 | WSW | 52 | 36 | 1959 | | 5.2 | 10 | 11 | 9 | 8 | * | 8 | 1 | 3 | 0 | * | 0 | 836.9 |
| J | 87.1 | 54.9 | 71.0 | 104 | 1954 | 30 | 1972 | 13 | 199 | 0.95 | 3.05 | 1951 | 0.11 | 1971 | 1.51 | 1977 | 0.0 | | 0.0 | | 70 | 33 | 26 | 55 | 10.1 | WSW | 52 | 25 | 1974 | | 4.1 | 15 | 11 | 5 | 7 | 0 | 9 | * | 11 | 0 | * | 0 | 839.8 |
| A | 85.6 | 53.5 | 69.6 | 99 | 1969 | 33 | 1977 | 17 | 159 | 0.57 | 1.52 | 1972 | 0.02 | 1950 | 1.00 | 1974 | T | 1964 | T | 1964 | 65 | 31 | 23 | 51 | 10.5 | SW | 50 | 25 | 1954 | | 4.2 | 14 | 10 | 7 | 5 | 0 | 6 | * | 9 | 0 | 0 | 0 | 839.5 |
| S | 74.1 | 43.3 | 58.7 | 93 | 1960 | 19 | 1965 | 229 | 40 | 0.87 | 3.28 | 1973 | 0.07 | 1956 | 2.01 | 1973 | 8.8 | 1965 | 4.5 | 1965 | 68 | 37 | 30 | 59 | 11.0 | WSW | 53 | 32 | 1965 | | 4.4 | 14 | 8 | 8 | 7 | * | 3 | 1 | 1 | * | 4 | 0 | 840.1 |
| O | 61.4 | 33.9 | 47.7 | 85 | 1957 | -3 | 1971 | 536 | 0 | 0.92 | 2.49 | 1962 | T | 1965 | 2.49 | 1962 | 13.1 | 1971 | 8.2 | 1970 | 69 | 45 | 41 | 64 | 12.2 | SW | 55 | 25 | 1954 | | 5.2 | 12 | 8 | 11 | 6 | 2 | * | 1 | 0 | 1 | 16 | * | 838.7 |
| N | 44.8 | 22.9 | 33.9 | 71 | 1965 | -14 | 1977 | 933 | 0 | 0.68 | 1.30 | 1956 | 0.07 | 1965 | 0.54 | 1955 | 19.9 | 1956 | 10.5 | 1977 | 69 | 53 | 55 | 66 | 14.5 | SW | 49 | 25 | 1970 | | 6.2 | 7 | 9 | 14 | 7 | 3 | * | 1 | 0 | 5 | 25 | 2 | 836.7 |
| D | 36.2 | 16.2 | 26.2 | 61 | 1973 | -31 | 1964 | 1203 | 0 | 0.49 | 1.04 | 1955 | 0.03 | 1952 | 0.47 | 1970 | 17.8 | 1967 | 8.2 | 1953 | 68 | 58 | 61 | 68 | 16.1 | SW | 63 | 20 | 1955 | | 6.3 | 8 | 8 | 15 | 7 | 3 | 0 | 1 | 0 | 13 | 29 | 5 | 835.4 |
| YR | 56.4 | 32.4 | 45.4 | 104 | JUL 1954 | -40 | JAN 1972 | 7555 | 458 | 11.22 | 5.59 | MAY 1971 | T | OCT 1965 | 3.00 | APR 1974 | 56.3 | APR 1973 | 16.5 | APR 1973 | 71 | 47 | 43 | 64 | 13.1 | SW | 81 | 25 | MAR 1956 | | 5.7 | 110 | 110 | 145 | 92 | 23 | 34 | 9 | 24 | 48 | 185 | 18 | 836.7 |

### SHERIDAN, WY — SHERIDAN COUNTY AIRPORT — MOUNTAIN — 44° 46' N — 106° 58' W — 3964 FT — 1977

| Month | Temperatures °F Normal Daily maximum | Normal Daily minimum | Normal Monthly | Extremes Record highest | Year | Record lowest | Year | Normal Degree days Base 65 °F Heating | Cooling | Precipitation in inches Water equivalent Normal | Maximum monthly | Year | Minimum monthly | Year | Maximum in 24 hrs. | Year | Snow, Ice pellets Maximum monthly | Year | Maximum in 24 hrs. | Year | Relative humidity pct. Hour 05 (Local time) | Hour 11 | Hour 17 | Hour 23 | Wind Mean speed m.p.h. | Prevailing direction | Fastest mile Speed m.p.h. | Direction | Year | Pct. of possible sunshine | Mean sky cover, tenths, sunrise to sunset | Mean number of days Sunrise to sunset Clear | Partly cloudy | Cloudy | Precipitation .01 inch or more | Snow, Ice pellets 1.0 inch or more | Thunderstorms | Heavy fog, visibility ¼ mile or less | Temperatures °F Max. (b) 90° and above | Max. 32° and below | Min. 32° and below | Min. 0° and below | Average station pressure mb. Elev. 3968 feet m.s.l. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | | | | 37 | | 37 | | | | | 37 | | 37 | | 37 | | 37 | | 37 | | 13 | 13 | 13 | 13 | 37 | 15 | 37 | 37 | | 37 | 34 | 37 | 37 | 37 | 37 | 34 | 37 | 37 | 13 | 13 | 13 | 13 | 5 |
| J | 33.5 | 8.5 | 21.0 | 70 | 1974 | -35 | 1963 | 1364 | 0 | 0.69 | 1.79 | 1972 | 0.12 | 1961 | 1.01 | 1972 | 26.3 | 1977 | 13.5 | 1972 | 68 | 60 | 63 | 68 | 7.8 | NW | 73 | NW | 1946 | 55 | 7.0 | 6 | 8 | 17 | 9 | 4 | 0 | 1 | 0 | 14 | 30 | 10 | 877.3 |
| F | 38.0 | 13.8 | 25.9 | 73 | 1951 | -31 | 1949 | 1095 | 0 | 0.77 | 2.68 | 1955 | 0.08 | 1977 | 1.10 | 1955 | 35.0 | 1955 | 11.0 | 1955 | 69 | 58 | 59 | 69 | 8.0 | NW | 70 | W | 1957 | 58 | 6.9 | 5 | 8 | 15 | 9 | 4 | * | 1 | 0 | 7 | 27 | 3 | 877.6 |
| M | 43.1 | 18.9 | 31.0 | 76 | 1943 | -23 | 1965 | 1054 | 0 | 1.21 | 3.26 | 1946 | 0.24 | 1960 | 2.25 | 1946 | 36.8 | 1954 | 13.3 | 1946 | 71 | 52 | 48 | 68 | 9.1 | NW | 66 | SW | 1963 | 61 | 6.9 | 5 | 10 | 16 | 11 | 4 | 0 | 1 | 0 | 6 | 28 | 2 | 873.6 |
| A | 56.3 | 30.9 | 43.6 | 87 | 1946 | -2 | 1975 | 642 | 0 | 2.12 | 4.80 | 1963 | 0.60 | 1960 | 3.84 | 1948 | 39.6 | 1955 | 26.7 | 1959 | 73 | 50 | 45 | 68 | 9.9 | NW | 66 | NW | 1947 | 58 | 6.8 | 6 | 8 | 16 | 11 | 3 | 1 | 1 | 0 | 1 | 20 | * | 876.6 |
| M | 66.0 | 40.2 | 53.1 | 95 | 1960 | 13 | 1954 | 375 | 7 | 2.45 | 5.20 | 1970 | 0.30 | 1958 | 2.04 | 1956 | 11.0 | 1943 | 7.3 | 1954 | 74 | 47 | 46 | 69 | 9.0 | NW | 71 | NW | 1946 | 58 | 6.6 | 6 | 10 | 15 | 12 | * | 5 | * | * | 0 | 6 | 0 | 876.5 |
| J | 74.3 | 47.8 | 61.1 | 100 | 1974 | 27 | 1951 | 168 | 51 | 2.99 | 9.54 | 1944 | 0.28 | 1971 | 3.44 | 1944 | 4.0 | 1969 | 4.0 | 1969 | 78 | 48 | 47 | 72 | 8.1 | NW | 66 | SW | 1952 | 63 | 5.8 | 8 | 11 | 11 | 11 | * | 10 | * | 2 | 0 | * | 0 | 877.3 |
| J | 86.1 | 54.6 | 70.4 | 106 | 1954 | 35 | 1971 | 28 | 195 | 1.07 | 3.78 | 1958 | 0.08 | 1959 | 2.28 | 1948 | 0.0 | | 0.0 | | 73 | 38 | 34 | 63 | 7.2 | NW | 73 | W | 1947 | 75 | 4.1 | 14 | 12 | 5 | 7 | 0 | 10 | * | 9 | 0 | 0 | 0 | 879.9 |
| A | 85.3 | 53.0 | 69.2 | 105 | 1949 | 34 | 1966 | 31 | 161 | 0.95 | 3.02 | 1968 | T | 1970 | 1.71 | 1943 | 0.0 | | 0.0 | | 67 | 34 | 30 | 56 | 7.3 | NW | 72 | NW | 1945 | 74 | 4.2 | 14 | 11 | 6 | 7 | 0 | 7 | * | 10 | 0 | 0 | 0 | 879.6 |
| S | 72.9 | 42.9 | 57.9 | 100 | 1940 | 15 | 1965 | 245 | 32 | 1.28 | 3.08 | 1951 | 0.06 | 1964 | 1.33 | 1947 | 9.5 | 1970 | 5.5 | 1970 | 71 | 43 | 39 | 63 | 7.5 | NW | 66 | NW | 1945 | 67 | 4.9 | 12 | 9 | 9 | 7 | * | 3 | * | 1 | 0 | 4 | 0 | 881.0 |
| O | 62.5 | 33.1 | 47.8 | 91 | 1963 | 1 | 1971 | 533 | 0 | 1.02 | 3.16 | 1971 | 0.02 | 1965 | 1.91 | 1974 | 14.8 | 1971 | 8.4 | 1977 | 70 | 47 | 46 | 66 | 7.5 | NW | 66 | NW | 1958 | 63 | 5.5 | 11 | 8 | 12 | 7 | 1 | * | * | 0 | 1 | 18 | 0 | 879.9 |
| N | 46.0 | 20.8 | 33.4 | 78 | 1975 | -25 | 1959 | 948 | 0 | 0.92 | 2.23 | 1942 | 0.15 | 1951 | 0.86 | 1942 | 25.8 | 1964 | 12.0 | 1942 | 72 | 57 | 60 | 70 | 7.8 | NW | 84 | SW | 1949 | 52 | 6.7 | 6 | 8 | 16 | 8 | 3 | * | 1 | 0 | 4 | 28 | 2 | 878.4 |
| D | 37.6 | 13.4 | 25.5 | 71 | 1941 | -30 | 1972 | 1225 | 0 | 0.69 | 2.03 | 1955 | 0.23 | 1957 | 0.54 | 1946 | 27.6 | 1955 | 8.6 | 1960 | 71 | 61 | 65 | 70 | 7.6 | NW | 63 | NW | 1958 | 53 | 6.7 | 6 | 8 | 17 | 9 | 4 | 0 | 1 | 0 | 12 | 30 | 7 | 877.0 |
| YR | 58.5 | 31.5 | 45.0 | 106 | JUL 1954 | -35 | JAN 1963 | 7708 | 446 | 16.16 | 9.54 | JUN 1944 | T | AUG 1970 | 3.84 | APR 1948 | 39.6 | APR 1955 | 26.7 | APR 1955 | 71 | 50 | 48 | 67 | 8.1 | NW | 84 | SW | NOV 1949 | 62 | 6.0 | 99 | 111 | 155 | 108 | 23 | 36 | 6 | 22 | 46 | 192 | 24 | 877.9 |

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

Table-3-2 High-Low Population Forecasts, Gillette and Campbell Counties, Wyoming (1976-1990). From Campbell County Chamber of Commerce, 1979.

| | | | | | | | | Average Annual Change: 1976-1980 | | Average Annual Change: 1980-l 990 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low Forecast | 1976 | 1977 | 1978 | 1979 | 1980 | 1985 | 1990 1979 1980 1985 1990 | -- Amount | Percent | Amount | Percent |
| Gillette Urbanized Area' | 15,720 | 18,540 | 20,450 | 23,240 | 24,460 | 28,540 | 31,320 | 1,748 | 11.1 | 686 | 2.8 |
| Campbell County | 20,620 | 23.750 | 26,080 | 29.200 | 30,510 | 34,860 | 37,950 | 1,978 | 9.6 | 744 | 2.4 |
| High Forecast | | | | | | | | | | | |
| Gillette Urbanized Area' | 15,720 | 18,540 | 21,500 | 24,100 | 28,660 | 42,730 | 43,540 | 2,588 | 165 | 1.488 | 5.2 |
| Campbell County | 20,620 | 23,750 | 27,040 | 30,610 | 36,490 | 54,020 | 54,700 | 3.174 | 154 | 1.821 | 5.0 |
| Difference High-Low-Total | | | | | | | | | | | |
| Amount | | | 960 | 1,410 | 5,980 | 19,160 | 16,750 | | | | — |
| Percent | — | | 4.5% | 5.8% | 17.6% | 55.0% | 44.1% | | | | — |

'Gillette and Campbell County Planning Area
Source: Gladstone Associates.

Table 3-3 Summary of Major Structural Events Affecting Powder River Basin During the Laramide Orogeny (Curry, 1971).

1. Late Maestrichtian Lance : 'Subsidence increased southward but there is no evidence of local basin subsidence.

2. Early Paleocene Tullock: First slight subsidence was present in the southern and southwestern parts of the basin. but there was no prominent subsidence along the axis of the basin.

3. Middle, Paleocene Lebo: First strong subsidence along the axis of the Powder River Basin is found but there is no evidence of influx of coarse clastics from adjacent uplifts. Middle Paleocene marks the first strong evidence of the Laramide Orogeny.

4. Late Paleocene Tongue River: Strong subsidence continued along the axis of the basin and the influx of sandstone is the first indication of uplift and erosion of the adjacent mountain uplifts.

5. Eocene Wasatch: Mountains continued to be uplifted and were eroded to, their Precambrian cores. Conglomerate fans along the flank of the Bighorn Mountains were deposited and subsequently deformed.

6. Oligocene White River: Orogenic movements abruptly stopped before the Oligocene and White River volcanic rocks filled the basin and buried the Precambrian cores of the mountains.

7. Post Oligocene: Moderate subsidence of the mountain uplifts along faults, caused local tilting of the White River toward the sinking mountain blocks.

Table 3-4 Geologic Formations and Potential Water Supply (From Hodson, Pearl and Druse, 1973)

| ERA | SYSTEM | SERIES | GEOLOGIC UNIT WEST SIDE BASIN | GEOLOGIC UNIT EAST SIDE BASIN | AVAILABILITY AND CHEMICAL QUALITY OF GROUNDWATER |
|---|---|---|---|---|---|
| CENOZOIC | TERTIARY | Eocene | Wasatch Formation | | Yields water from lenticular sandstone, and to a lesser extent from jointed coal and clinker beds. Yields can be expected to range from 10 to 50 gpm in north part of basin becoming generally greater southward with 500 gpm or more possible in south part of basin. Well 50-72-35dd near Gillette had a specific capacity of about 4 gpm per foot of drawdown. Seven wells on the Buffalo Ranch (T. 44N., R. 72W.) had specific capacities, as reported on drillers' logs, ranging from 5 to 14 gpm per foot of drawdown. Yields of 200 gpm or mort may be possible locally from Moncrief and Kingsbury Conglomerate Members in northwest part of basin, but these rocks characteristically abut against the mountain flanks, are moderately dissected, and are probably largely drained. Dissolved solids range from less than 200 to more than 8.000 mg/l, but commonly range between 500 and 1,500 mg/l. No relation of dissolved solids to depth is discernible, but water mineralization decreases in general southward. Sodium sulfate and sodium bicarbonate are the most dominant water types |
| | | Paleocene | Fort Union Formation | | Yields water from fine-grained sandstone, jointed coal, and clinker beds. Maximum yields are about 150 gpm. Average specific capacity of four wells in southwest Crook County was 0.3 gpm per foot of drawdown, and for four wells at Wyodak coal mine in Campbell County was 0.9 gpm per foot of drawdown (Whitcomb and Morris, 1964, table 1 and p. 40). Well 50-72-22cac near Gillette had a specific capacity of 0.7 gpm per foot of drawdown (Littleton, 1950, p. 14). Average specific capacity for 85 wells in Sheridan County computed from yield-drawdown data from drillers logs was 0.42 gpm per foot of drawdown (Lowry and Cummings, 1966, p. 21). Dissolved solids range from about 200 to more than 3,000 mg/l, but commonly range between 500 and 1,500 mg/l. Water type is mostly sodium bicarbonate, and to a lesser extent sodium sulfate. |
| MESOZOIC | CRETACEOUS | Upper Cretaceous | Lance Formation | | Generally yields less than 20 gpm, but yields of several hundred gallons per minute may be possible from the complete section of the formatlon. Most wells have been drilled in outcrops of the Lance for domestic and stock purposes and tap only a small part of the formation. The specific capacity of three wells in Crook County ranged from 0.4 to 1.7 gpm per foot of drawdown (Whitcomb and Morris, 1964, p. 15). Dissolved solids range from about 200 to more than 2,000 mg/l, but commonly range between 500 and 1,500 mg/l. No dominant water type is prevalent. |
| | | | | Fox Hills Sandstone | Yields of as much as 200 gpm are available from sandstone beds in east part of basin. Several wells south of Rozet produce about 200 gpm from the Fox Hills for water flooding. Well 56-71-15dd, Campbell County, flows 75 gpm from a depth of about 2,000 feet, and has a shut-in pressure of 54 psi (pounds per square inch) at the surface. Maximum yields in west part of basin will probably be less than 100 gpm. Well 40-78-15abb, Natrona County, had a specific capacity of only 0.37 gpm per foot of drawdown (Crist and Lowry, 1972, p. 61). Dissolved solids are mostly less than 1,000 mg/l in east part of basin, but generally range between 1,000 and 2,000 mg/l in west part. No dominant water type is prevalent. |
| | | | Lewis Shale | | Lewis Shale — Sandy zones may yield as much as 10 gpm, but most of the formation does not yield water. |
| | | | Mesaverde Formation | | Mesaverde Formation — Yields of as much as 50 gpm are possible from sandstone beds, and as much as 200 gpm where fracturing has increased the permeability, generally near geologic structures. Well 37-78-7dcd, Natrona County, yields about 120 gpm. Dissolved solids can be expected to range from about 300 mg/l to more than 2,000 mg/l. Most water will be sodium sulfate type. |

# 4. COAL RESOURCES

## 4.1 REGIONAL SETTING

The Powder River Basin contains the most important coal deposits in the United States. Because of their size and availability, these deposits, by themselves, could make up the entire near- and intermediate-term energy shortfall of the U. S. This statement is deliberately made in order to stress the critical significance of these deposits. The significance of these deposits is due to their great size, the number and thickness of individual beds, their relatively shallow depth, and their occurrence in an area of relatively low land value and easily mitigated environmental constraints.

The Coal resource of the basin, greater than in any other region in the country, has been calculated from available subsurface data to be 1.3 trillion tons. Most of this resource is in thick beds which are relatively near-surface, with most coalbeds being at a depth of 2500 feet or less, even in the basin center (Elmer Schell, U. S. Geological Survey, oral communication).

Most of the earlier coal-resource calculations were restricted to outcrop areas along strike of the coalbeds, and for relatively short distances downdip. Until recently, little was known about the extent of the coalbeds downdip to the center of the Powder River Basin. For that reason, early calculations of coal-resources grossly understate the coal that almost certainly exists (Averitt, 1975).

In 1950, Berryhill, et al, estimated the total amount of coal-resources in the Wyoming portion of the Powder River Basin to be 94.88 billion short tons. In 1975, Glass updated that estimate to a total of 110 billion short tons. These figures include identified resources of coal 2.5 feet and thicker, in measured, indicated and inferred categories between 0-3000 feet of cover. More recently, Mapel and Swanson (1977) have estimated the coal resource of the Montana portion of the Powder River Basin to be 178 billion short tons, to a depth of 1500 feet and Glass (1976) based on information from Averitt (1975) and Hamilton, et al, (1975) has updated his previous figure for the Wyoming portion of the basin to include an additional 500 billion short tons of undiscovered--speculative and hypothetical--resources to as much as 6000 feet in depth. The current combined estimates for the Wyoming and Montana portions of the basin total 788 billion tons of coal.

The USGS is currently performing an extensive study of the coal resources in the Powder River Basin. In this evaluation, oil and gas well logs have been examined and coal resources determined for the basin in depth increments of 500 feet. However, subsurface control for this evaluation is limited to the eastern two-thirds of the basin, where oil and gas exploration has been concentrated. These detailed studies show that the Powder River Basin of Wyoming-Montana contains 1.3 trillion tons of coal--a substantial increase over previous figures (Rupert, et al, 1975). Strippable coal reserves for Wyoming and Montana are shown in Tables 4-1 and 4-2.

Subsurface logs indicate that strata in the basin contain five major coal zones, which generally are concentrated in a vertical section of 1000-1200 feet. In addition, these studies have indicated that probably 50 percent or more of the total coal in the basin would be in beds 15 to 50 feet thick and 30 to 40 percent in beds greater than 50 feet thick. As yet, no detailed evaluation has been made by the USGS on an individual bed basis (Rupert, et al, 1975).

Coal in the Powder River Basin ranks as lignite A through subbituminous A. The American Society for Testing and Materials (1964, p 74) classifies coals on a moist, mineral-matter free basis with a calorific value of 6300-8300 Btu per pound as lignite A, 8300-9500 Btu as subbituminous C, 9500-10500 as subbituminous B, and 10,500-11,500 as subbituminous A. Lignites in the Powder River Basin are restricted to a small area in the northeast.

As-received heat values from coals in the Montana portion of the basin range from 6500 Btu per pound in the Knowlton deposit, just outside the northeast boundary of the basin, to 9850 Btu in the Decker deposit on the west side of the basin. In the Wyoming portion of the basin, the coals range from 7550 Btu per pound in Converse County to 9300 Btu per pound in the Sheridan area. The average of the Wyoming coals is relatively low--8300 Btu per pound as-received (Glass, 1978; Matson and Blumer, 1973). Typical as-received analyses for some of the major coalbeds are shown in

Table 4-3. Unfer (1951), as quoted by Glass (1978) has summarized the general distribution of the various ranks of coal:

> "While the older coals in any given field are generally higher in rank than the younger beds, the rank of individual beds also seems to increase toward the troughs of the structural basins. Both of these variations in rank have been attributed to increases in depth of burial."

Generally, Powder River Basin coals are low in sulfur and have low to moderate ash contents, although the ash content can vary considerably. The coals usually have an as-received moisture content of 20 to 30 percent, and volatile matter and fixed carbon contents of 30-40 percent. The coal loses moisture, slacks, and can ignite spontaneously when exposed to air.

Most of the thick coalbeds occur in the upper member--the Tongue River Member--of the Fort Union Formation, and the overlying Wasatch Formation. These two sequences reach a maximum thickness of 3970 feet near the Buffalo-Lake De Smet area (Curry, 1971); however, most of the thick coalbeds range from surface exposures to less than 2500 feet in depth. Coalbeds do occur in the lower members of the Fort Union Formation, as well as the Lance and Mesaverde Formations (Figure 4-1), but they are generally thinner and less continuous. Some of these older coalbeds crop out in the southwestern portion of the Powder River Basin, near Glenrock and Douglas.

Fort Union and Wasatch time was characterized by cyclic deposition in a near-shore environment that was periodically being subjected to uplift and subsidence. Periods of stability led to the development of extensive coal-forming swamps. Sedimentary rocks which are characterized by repeating sequences of sandstones overlain by shale, a thick coalbed and then shale are thought to have formed in an extensive flood plain environment, with the open sea to the east and northeast. The thick sandstone beds were probably deposited in littoral environments and the principal coalbeds formed in large coastal swamps and marshes.

The general structural configuration of the continental coal-bearing formations is one of a gentle, asymmetrical syncline. The rocks, of Late Cretaceous and Tertiary age, reach a maximum thickness of nearly 8000 feet at the basin axis. The formations dip as much as 10 to 25$^{\circ}$ along the western margin of the basin, near the Bighorn Uplift, and flatten to less than 1$^{\circ}$ in the interior of the basin. Faults with maximum displacements of

100-400 feet occur along the western margin of the basin near the Bighorn Uplift, but are less common elsewhere in the basin.

Several joint and fracture studies have been done in coal-bearing rocks of the Powder River Basin; the results of these studies are summarized by Henkle, Muhm and DeBuyl (1978) and illustrated here in Figures 4-2 and 4-3 and Table 4-4. In summary, Stone and Snoeberger (1976) studied the Felix coalbed in the Hoe Creek area, 20 miles southwest of Gillette. They found fracture orientations to be subparallel to the regional strike and dip of the coal-bearing rocks. They also noted that the fracture set which is subparallel to the regional dip is twice as permeable as the fracture set which is subparallel to the regional strike. Glass (1976) reported similar joint orientations in the Badger and School coalbeds in the southern Powder River Basin. He also reported two pairs of joint orientations in the Anderson-Canyon coal in the Gillette area. They consist of two sets (one pair) which subparallel the regional strike and dip--NW and NE respectively--and two sets (another pair) which trend NS-EW. The Tongue River member in the Sheridan-Decker area of Wyoming and Montana was studied by Lee, Smith and Savage (1976), who reported three major joint orientations. The N45$^{o}$W and N37$^{o}$E pair are subparallel to the regional strike and dip; and the third set trends N13$^{o}$E. Henkle, Muhm and DeBuyl (1978) studied a small area near Gillette, and found two sets of fractures. They concluded that at least one of the pairs of cleats and joints in their study area was inherited from existing joint patterns in the underlying Precambrian basement rocks, and formed as a result of tensile stresses following uplift and erosion of overlying sediments. Another joint pair in their area was found to be subparallel to the regional strike and dip of the coal-bearing rocks. These workers noted excellent correlation between cleat orientation of coal seams and joint orientation of the overburden.

The total number of coalbeds in the Powder River Basin is difficult to determine because the beds split, coalesce, and are commonly discontinuous, with beds pinching out and new beds appearing. In the Sheridan area of Wyoming, as many as 11 persistent coalbeds occur in the Wasatch Formation. In other areas, as many as 12-18 coalbeds occur, most of them within the Fort Union Formation. Most of the Wasatch beds occur under less than 200 feet of overburden. However, the Wasatch and Fort Union Formations together reach a maximum thickness of 3970 feet in the Buffalo area.

Two of the largest coalbeds in the basin are the Wyodak-Anderson and the Lake De Smet bed. The Wyodak-Anderson coalbed crops out over a north-south distance of 120 miles in the Gillette Coal Field. It, and the beds correlative to it, persist downdip to the deepest part of the Powder River Basin. The Wyodak-Anderson bed is locally up to 150 feet thick, but averages 50 to 100 feet in thickness. Based on these figures, the bed contains at least 100 billion tons of coal to a depth of 2000 feet. This is the largest tonnage in a single continuous coalbed anywhere in the U. S. (Averett, 1975).

The Lake De Smet bed, which occurs in the Buffalo Coal Field is thought to be the thickest coalbed in the U. S. and second thickest in the world. It is 15 miles in length, 70 to 220 feet thick and 0.5 to 2 miles wide (Obernyer, 1978).

## 4.2 COAL RESOURCES BY AREA

The Powder River Basin contains 21 coal fields (shown in Figure 4-4). In Wyoming, coal field boundaries have been clearly defined. In Montana, however, coal fields and their boundaries are much less clearly defined. The coalbeds in each field are typically given different names, and until recently, very little correlation between these fields had been attempted. Even now, the nomenclature is confusing. We have attempted here to synthesize the enormous amount of data available on the Powder River Basin coals, but were somewhat limited by the casual and occasionally conflicting use of coalbed names in the literature and within the energy industry. It is hoped that current mapping efforts by the USGS may help to clearly define the nomenclature as well as the extent of the coalbeds.

Some correlations have been made recently between some of the coal fields. Glass (1976) has shown in a fence diagram the current understanding of the eastern and western coal fields of the Wyoming portion of the basin (Figure 4-5), Mapel and Swanson (1977) have correlated the coal fields of the Montana portion, and Olive (1957) presents a very general correlation between the Montana and Wyoming coal fields (Figures 4-6 and 4-7). The coals of the southern Powder River Basin, however, have not been correlated positively with each other, or with coalbeds to the north. In order to simplify the discussion of the coalbeds, we have divided the Powder River Basin into the four sections shown in Figure 4-4. Each will be discussed separately, and when correlations between these sections have been made, they will be pointed out.

There are 14 operating coal mines in the Powder River Basin. Twenty more are in various stages of permit and construction (Table 4-5). Most of these mines are in the Gillette and Sheridan areas of Wyoming (Figure 4-8). There are 19 proposed and existing mines along the north-south trend of the Wyodak-Anderson coalbed in Campbell County.

This was not intended to be an exhaustive compilation of literature available on the coalbeds. It does, we hope, summarize the general character, extent, and quality of the coals. Since most studies in the Powder River Basin have been directed toward defining the strippable reserves of coal, detailed information on the deeper coalbeds is generally lacking. We have included such information on these that was available.

### 4.2.1 Eastern Coal Fields

Coal fields here grouped into the eastern fields include the Gillette, Pumpkin Buttes, Powder River, Little Powder River, and Spotted Horse (Figure 4-4). These fields, mostly in Campbell County, are grouped together because they all lie along the central portion of the very gently dipping eastern limb of the asymmetrical syncline containing the non-marine, coal-bearing strata of the Fort Union and Wasatch Formations (Figure 3-8). Regional dip of these beds is only 0.4 degrees to the west, as measured along a 25-mile east-west section of the Wyodak coalbed (contact between the Fort Union and Wasatch Formations in recent USGS mapping). Because of small folds within Fort Union and Wasatch strata, dips generally in the range of 2 to 4 degrees occur locally, however, in individual coalbeds.

In the U. S. Geological Survey bulletins, where the five coal fields comprising the eastern fields of Powder River Basin are principally described, coalbeds identified and discussed are as follows, with the youngest beds being first:

- o Spotted Horse Field (Olive, 1957)

  Eleven named beds - Ulm No. 1, Ulm No. 2, Scott, Felix, Arvada, Roland, Smith, Anderson, Dietz No. 1, Canyon and Wall.

- o Pumpkin Buttes Field (Wegemann, et al, 1928)

  Eight named beds - A through H.

- o Gillette Field (Dobbin and Barnett, 1927)

  Nineteen named beds, as composited from exposures in the northern, central, and southern parts of the field - A through S.

- o Little Powder River Field (Davis, 1912)

  Ten named beds - A through J.

- o Powder River Field (Stone and Lupton, 1910)

  Five named beds - Lower Ulm, Felix, Arvada, Roland, and Smith.

In the above reports, letter names of beds are restricted to the individual field, and are not directly correlative -- A for A or B for B -- to other fields. For example, Felix bed which has its type locality in the Powder River Field, is B bed in the Gillette Field (Dobbin and Barnett, 1927) and E bed in the Pumpkin Buttes Field (Wegemann, et al, 1928).

In current mapping by the U. S. Geological Survey in Campbell County, still a different nomenclature set has been devised. In a 25-mile east-west section in the Caballo Creek area south of Gillette, Grazis (1977) has identified from drill hole data the following 25 beds, including splits (youngest listed first): A, Lower Ulm, Scott; F or Felix (splits $F_1$ & $F_2$); C", C', C, Wyodak (splits $W_1$, $W_2$ & $W_3$), M, N, O, P (splits $P_1$ & $P_2$), Q, R, S (splits $S_1$ & $S_2$), T, U, V, and X (splits $X_1$ and $X_2$).

Stratigraphic columns for coalbeds occurring in Campbell County coal fields, recently compiled by the Wyoming and U. S. Geological Surveys, are shown in Figure 4-9. Typical cross-sections through the Wasatch and Fort Union coalbeds are shown in Figure 4-10. A typical log response is shown in Figure 4-11, and average analyses of coal samples from Campbell County are given in Table 4-6. The thicknesses and characteristics of some of the Fort Union coalbeds compiled from seven recent U. S. Geological Survey quadrangle maps is given in Table 4-7.

#### 4.2.1.1 Principal Wasatch Coalbeds

Ulm No. 1 bed. The Ulm No. 1 bed, originally named by Taff (1909) in the Sheridan Field, is stratigraphically the highest of the named coalbeds in the eastern coal fields. Ulm No. 1 is identified by name by Olive (1957) as occurring only at one location in the Spotted Horse Field. This one remnant that has escaped erosion occupies an acre of land atop a high butte in the southern part of the field (Sec. 14, T53N, R75W). Here, the bed is 11 feet thick.

A bed about two feet thick, correlative to Ulm No. 1, occurs in a small area on the divide between Powder and Belle Fourche Rivers in the Pumpkin Buttes Field. Wegemann, et al, (1928) identified this bed as A bed in the sequence of eight beds (A-H) they described for the field. Grazis (1977) describes a similar two-foot thick bed as being the highest bed, both stratigraphically and topographically, in the Caballo Creek area southwest of Gillette (Pleasantdale quadrangle). To the west, Ulm No. 1 evidently thickens gradually to where it becomes an important economic bed in the Sheridan and Buffalo fields.

Ulm No. 2 bed. Ulm No. 2 bed, described in Olive (1957) for occurrences in the Spotted Horse Field, is 75 feet below Ulm No. 1. The bed crops out near the tops of divides in the southern portion of the field. In many places the bed has burned, forming a thick erosion-resistant clinker cap for many of the highest ridges and buttes. Where unburned, the bed ranges in thickness from 4 to 22 feet; an average thickness is probably about 12 feet in the Spotted Horse Field.

South of the Spotted Horse Field, coalbeds in the Powder River and Pumpkin Buttes Fields, occurring at the same stratigraphic horizon as Ulm No. 2, are identified as the Lower Ulm and B beds, respectively. As in the Spotted Horse Field, the Lower Ulm occurs high on buttes and divides, is commonly burned, and the resulting clinker caps the ridges. In the Powder River Field the Lower Ulm ranges in thickness from 10 to 15 feet.In the Pumpkin Buttes Field the correlative B bed--which lies 80 to 100 feet below A bed--ranges from 6 toll feet and averages 10 feet in thickness. To the west, Ulm No. 2 correlates with the Healy bed in the Sheridan-Buffalo areas.

Haddock, Kent and Bohor (1976) identify two new coalbeds, the Truman and Parnell beds which crop out in the Croton and Truman Draw Quadrangles. The Truman bed is 4 to 20 feet thick in one or two benches. The Parnell bed splits from the base of the Truman bed near the Parnell Ranch and is thought to be equivalent to the Ulm No. 2 of the Sheridan Field. It contains 2.7 to 12 feet of coal in one to four benches, and is as much as 80 feet below the Truman bed.

Scott bed. The Scott bed has its type locality in the southern part of the Spotted Horse Field (NE1/4, Sec. 14, T53N, R74W) about one mile northwest of the Scott homestead, for which it is named. The bed, about 65 feet below Ulm No. 2, is persistent throughout the southern part of the field. Average thickness is less than 4 feet; maximum thickness in the field is 10 feet.

To the south, in the Pumpkin Buttes Field, Wegemann, et al (1928), describe the outcrops of C bed--correlative to the Scott bed--in T47N, R74W, as comprising two benches of coal, each about 2 feet thick, separated by a thin shale parting. Grazis (1977) identified the Scott bed in a drill hole in the Caballo Creek area (west edge of the Pleasantdale quadrangle) as being 7 feet thick.

The three beds--Ulm No. 1, Ulm No. 2, and Scott--are referred to as the upper Wasatch coal zone.

The Daly coalbed was named by McLaughlin and Hayes (1973) for exposures in the Olivia NW (Townsend Spring) quadrangle, where it is 50 to 150 feet below the Scott bed. It is a zone with as many as six separate benches of coal, containing a total of 1.4 to 12.4 feet of coal. Partings between the benches are as much as 8 feet thick but usually less than 2 feet.

Felix bed. The Felix bed, including its two principal benches or splits, is the middle Wasatch coal zone. For much of the eastern coal fields area, it comprises the principal coal resource of the Wasatch Formation. The bed was named by Stone and Lupton (1910) for a thick exposure in a stream bed at Felix, a station on the Burlington Railroad.

In exposures available to Stone and Lupton, in the Powder River Field, the Felix was indicated to comprise from two to four benches with total coal thickness of 6 to 30 feet. To the north, in the Spotted Horse Field, Olive (1957) stated that the Felix has an average thickness of 15 feet and a maximum thickness of 33 feet. In the Gillette Field, Dobbin and Barnett (1927) showed the B, or Felix, bed gradually thickening across the field from south to north, with thickness ranging in the south from 1 to 14 feet, in the central portion of the field from 5 to 15 feet, and in the north from 4 to 21 feet. Glass (1978), however, evidently based on recent data available from mining operations and drill hole logs, states that bed thicknesses as great as 50 feet occur in the southern Gillette Field.

In the Caballo and Hoe Creeks area, about 20 miles south of Gillette, Grazis (1977) describes the Felix bed as occurring mostly in two benches, $F_1$ and $F_2$. The upper bench, $F_1$, ranges in thickness from 5 to 12 feet and averages 20 to 25 feet. The parting separating $F_1$ and $F_2$ ranges from 0 to 80 feet; where the parting is absent and the two benches are coalesced into a single bed, the Felix is referred to as the F bed by the USGS. It is the Felix bed on Hoe Creek that is being utilized for the Lawrence Livermore Laboratories experiments in underground gasification.

The Felix in outcrops south of Gillette is 60 to 100 feet below Ulm No. 2 (Grazis, 1977); to the north in the Spotted Horse Field, it is 190 feet below the Scott at the Scott's type locality, and 280 feet below the Scott, a few miles to the west (Olive, 1957).

bed(s). The C bed coal zone comprises the lower of the three coal zones of the Wasatch Formation. The C bed was named by Dobbin and Barnett (1927) for exposures in the Gillette Field and was stated by them to consist of a series of individual coal lenses separated by numerous shale partings. The most definitive description of this coal zone is by Grazis (1977) from surface and subsurface data in the Caballo Creek study area. Here, three beds of economic value occur--the C", C' and C beds, with C" being the uppermost. The C" bed is 100 to 350 feet below the Felix; C' is 80 to 90 feet below C"; and C--most valuable of the three beds--is 60 to 160 feet below C'. As throughout the entire coal-bearing stratigraphic section, along the eastern line of the basin, non-coal intervals both between and within coal zones thicken to the west, towards the basin center.

Within the four-quadrangle Caballo Creek study area (from east to west; Saddle Horse Butte, Gap SW, Scaper Reservoir, and Pleasantdale), bed thickness ranges from 0 to 6 feet and averages 3 feet for C" and ranges from 0 to 14 feet for C'. The C bed within the quadrangle area has a maximum thickness of 42 feet; however, only 4 to 5 miles to the west, subsurface data show the bed to be 75 feet thick (Secs. 12 & 13, T47N, R75W; Double Tanks quadrangle). Depth of overburden for C bed within the four-quadrangle area ranges from about 100 feet on the east, to 1350 feet on the west. An analysis of a drill-core sample of C bed on an as-received basis, is: moisture, 9.7 percent; volatile matter, 39.6 percent; fixed carbon, 42.8 percent; ash, 7.9 percent; sulfur, 1.4 percent; and heating value, 10,500 Btu/lb (Grazis, 1977).

#### 4.2.1.2 Principal Fort Union Coalbeds

Arvada bed. The Arvada bed is placed by Olive (1957) within the Wasatch Formation, a few feet above its base. The Wyoming Geological Survey, however, identifies the Arvada as the uppermost bed within the Fort Union Formation (Breckenridge, et al, 1974, Figure 4-9; Glass, 1976, Figure 4-5). Evidence for placing the Arvada within the Fort Union is that the unconformity, which separates Fort Union from Wasatch strata, cuts the Arvada bed. The Wyoming Geological Survey stratigraphic placement will be accepted in this report. The bed was named by Stone and Lupton (1910) for a small coal mining operation at Arvada, on the Powder River. The Arvada is underlain by a fossiliferous sandstone, abundant with gastropods, which acts as a marker for the Arvada. Stone and Lupton (1910) traced the Arvada through outcrops along the Powder River, Clear Creek, and Wildhorse Creek, with average thicknesses ranging from 5 to 10 feet; the Arvada is placed by Stone and Lupton 375 to 400 feet below the Felix.

Roland bed. The Roland bed has been positively identified only in the Spotted Horse Field in the eastern coal fields. In the Spotted Horse Field, the Roland is 65 feet below the Arvada bed, is quite lenticular, and has a maximum thickness of 6 feet (Olive, 1957). The bed occurs mostly in the area west of Powder River and Clear Creek. The bed thins to the east, but thickens to the west to become economically important in the Sheridan Field.

The Roland bed has been the subject of several misidentifications or miscorrelations in the older literature. Stone and Lupton (1910) miscorrelated a local bed in the Powder River Field with the Roland (Olive, 1957). A major misidentification that has caused much confusion throughout the years, was by Dobbin and Barnett (1927) when they miscorrelated D bed (the Anderson, Wyodak-Anderson, or Wyodak bed) of the Gillette Field with the Roland.

Smith bed. The Smith bed, occurring principally in the Spotted Horse and western Little Powder River Fields, is about 180 feet below the Roland bed (Olive, 1957). Where present in these fields, the bed mostly ranges in thickness from 5 to 12 feet. The Smith bed was miscorrelated with the stratigraphically lower Canyon bed of the Gillette area for many years (Glass, 1978).

Swartz bed. The Swartz bed is shown in three recent quadrangle maps by the USGS in the southern part of the Spotted Horse Field. It is combined with the Anderson bed in the east portion of the field and separates to as much as 500 feet above the Anderson westward. In the three quadrangle area, it is 9 to 35 feet thick.

Anderson bed. The Anderson is the most persistent and widespread coalbed in the Powder River Basin. It is most prominently developed along the eastern rim of the basin, in Campbell County. Elmer Schell (Area Geologist, USGS Conservation Division; personal communication) states that he has personally traced the continuous outcrop line of the Anderson from the Montana-Wyoming border southward for over 120 miles. For part of this area, the Anderson coalesces with the underlying Canyon bed to form the thick Wyodak, or Wyodak-Anderson, bed centered at Gillette. The Wyodak bed is discussed separately, following the Canyon bed.

To the west, the Anderson--or beds correlative to it--has been traced through drill-hole geophysical logs to the deep, central portions of the basin. In the Sheridan Field on the western portion of the basin, the Anderson is correlated with the Dietz No. 1 bed, or to the bed immediately above it. In the northern extension of the Sheridan Field in the Decker area of Big Horn County, Montana, the Anderson is identified as a separate bed above Dietz No. 1. A few miles northwest of the Decker Mine, the

Anderson, Dietz No. 1 and Dietz No. 2 all combine to form a superbed 80 feet thick.

In the Spotted Horse Field, the Anderson, an average 160 feet below the Smith bed, ranges in thickness mostly from 6 to 32 feet, where unburned. The bed averages 15 feet in thickness and contains the largest reserves of any bed in the field (Olive, 1957). Over much of the north-central and north-eastern portion of the field, the Anderson is burned, producing a clinker bed as much as 100 feet thick.

In recent U. S. Geological Survey mapping in seven quadrangles of the Spotted Horse and Powder River Coal Fields, the Anderson ranges from 5 to 42 feet thick, and averages 20 to 33 feet thick (Table 4-7).

Dietz bed. The Dietz bed is as much as 200 feet below the Anderson in seven recent quadrangle maps. In places the Dietz is combined with the overlying Anderson or underlying Canyon, or both. Where separate, it ranges from 6 to 46 feet in thickness. In the Spotted Horse Field, Olive (1957) describes it as a series of discontinuous lenses.

Canyon bed. The Canyon coalbed is persistent over all but the southern and western edges of the basin and is as much as 225 feet below the Dietz in seven recent USGS quadrangle maps. It is the lowest of the beds that coalesce eastward to form the Wyodak "superbed". Where separate, the Canyon coalbed is 5 to 98 feet thick lenticular, and consists of 1 to 4 benches with thin partings of shale. The Canyon bed is correlated with the E bed of the southern part of the Gillette Field and with the Dietz No. 3 bed (Taff, 1909) of the Sheridan Field.

Wyodak bed. In this report, the Wyodak, or Wyodak-Anderson, bed is restricted to that area within which the Anderson bed coalesces with the underlying Canyon to form the classic "superbed" of the Gillette area. The bed is named after the Wyodak Mine, located 4.5 miles east of Gillette--Wyodak being a contraction of the state names Wyoming-Dakota.

To the north of the Gillette area, the Wyodak is thought to split into at least five beds, each ranging in thickness from 5 to 31 feet, and each being separated by shale or claystone partings that individually range in thickness from 4 to 33 feet (Glass, 1978). The Anderson would be the uppermost of these splits. To the south, the Wyodak splits into two beds--the upper bed being the Anderson, or D bed of Dobbin and Barnett (1927), and the lower bed being the Canyon, or E bed of Dobbin and Barnett. To the west, Glass (1978) describes the Wyodak as splitting into two beds--the Anderson and Canyon--with each bed being 10 to 65 feet thick. In recent mapping by the U. S. Geological Survey in the Caballo Creek study area south of Gillette (Grazis, 1977), the Wyodak, when coalesced into a single bed, is designated the W bed. Where it separates, three principal splits are designated $W_1$, $W_2$, and $W_3$, with $W_1$ being uppermost and $W_2$ being the thickest and most persistent bed.

Wyodak bed thickness probably averages about 70 feet throughout the Gillette region where the Anderson and Canyon are coalesced, with minimum thickness being about 25 feet (Glass, 1978) and maximum thickness about 150 feet (Averitt, 1975). The Wyodak, in most places, contains a parting that represents the Anderson-Canyon contact; the parting commonly is about 8 inches thick and about 38 feet above its base (Glass, 1978). At the Wyodak Mine, the bed averages 90 feet in thickness and has approximately 50 feet of overburden. At the Belle Ayr Mine, 15 miles southeast of Gillette, the bed has an average thickness of 70 feet, and only a few feet of overburden.

In an area of about 800 square miles, (40 miles N-S and 20 E-W) centered on Gillette, thickness of the Wyodak has been mapped from bore hole geophysical logs (Denson and Keefer, 1974). Within this area the Wyodak is calculated to contain 41 billion tons of coal, with 7 billion being within stripping depths; i.e., within 200 feet of the surface. Averitt (1975) estimates that the Wyodak, along with the Anderson bed to the north and south of Gillette, conservatively contains over 100 billion tons of coal. This makes the combined Wyodak-Anderson the largest deposit of coal in a single continuous bed in the United States, and one of the largest in the world. Once the full extent of the bed is known--in its extensions westward to basin center in the Sheridan and Buffalo fields and northwestward to the Decker Mine area in Montana--resource tonnage values will be increased substantially even above these figures.

Cook bed. The Cook coalbed is 25 to 350 feet below the Canyon in seven recent USGS quadrangle maps. It is 3 to 45 feet thick in one or two benches.

Wall bed. The Wall coalbed is 40 to 200 feet below the Cook in the recent USGS maps and 290 feet below the Canyon in the Spotted Horse Field (Olive, 1957). It occurs as one to four beds containing a total of 3 to 66 feet of coal. Average coal thickness is generally 9 to 38 feet (Table 4-7).

Pawnee beds. The Pawnee occurs as one or two beds 800 to 1700 feet below the Wall bed. The two Pawnee beds are 80 to 170 feet apart. The Upper Pawnee is 4 to 36 feet thick and may be split into two benches. The Lower Pawnee, 3 to 17 feet thick, is less extensive than the Upper Pawnee.

Cache bed. The Cache coalbed is 500 to 1800 feet below the Pawnee. It occurs in one to two benches totalling 4 to 33 feet in thickness. The Cache coalbed is 1000 to 2200 feet below the surface in southern Campbell county, and is the lowest named coalbed in the area. Recent quadrangle mapping by the USGS shows as many as six unnamed beds each 3 to 4 feet thick in a 300 to 400 foot section below the Cache (Table 4-7).

### 4.2.2 Western Coal Fields

The western Powder River Basin region includes the Sheridan, Buffalo, Barber, and Sussex Coal fields (Figure 4-4). In this region, as many as 11 persistent coalbeds occur in the Wasatch Formation of Eocene age and as many as 12 coalbeds occur in the upper half of the Fort Union Formation of Paleocene age. Stratigraphic columns for coalbeds in Johnson and Sheridan Counties are shown in Figures 4-12 and 4-13. Coals also occur in the lower half of the Fort Union, but are thinner and less persistent. Very thin and discontinuous coal lenses occur in the Lance Formation of Cretaceous age.

The coal fields of this region form a part of the western margin of the Powder River Basin. The major structural configuration is an asymmetrical syncline or trough, trending NW-SE, parallel to the Bighorn Mountain front, steeply dipping on the west flank, and gently dipping ($1$-$4^{\circ}$) on the east side. The deepest point along the axis is situated near Kaycee, 40 miles south of Buffalo in the Sussex Coal Field. However, during Tertiary time, when most of the coalbeds were formed, the point of greatest subsidence and deposition was the Buffalo-Lake De Smet area (Obernyer, 1979).

Major tectonic events of the Laramide Orogeny are evident in this region. During early Tertiary time, block faulting of the Precambrian basement rocks gave rise to the Bighorn Mountains on the west and the formation of the Powder River Basin on the east. At the same time, the overlying Paleozoic sediments were drape-folded over the more rigid Precambrian blocks. Foster, Goodwin and Fischer (1969) have suggested that a nearly vertical subsurface fault extends along the mountain front from the Casper Arch to Sheridan, with a maximum vertical displacement near Buffalo of 4000 feet. In addition, several local flank thrust faults occur along the eastern margin of the Bighorn Uplift. One of these, the Piney Creek Thrust, resulted in the formation of fanglomerates of the Moncrief Member of the Wasatch Formation near Buffalo. Obernyer (1978) suggests that formation of the very large Lake De Smet coalbed, which is a thick linear bed parallel to and near the Bighorn Uplift, may have been controlled by a basement fault, active during Eocene time.

Coals of the Wasatch Formation are lower subbituminous C to upper lignite in rank. Fort Union coals are only slightly higher in rank--generally subbituminous C. Typical analyses of these coals are shown in Tables 4-8, 4-9 and 4-10.

There are three existing coal mines in western Powder River Basin. The Black Mountain Mine is a three-man locally owned and operated mine near Sheridan. The Ash Creek Mine is a strip mine scheduled to begin operation sometime this year, 15 miles north of Sheridan. The Bighorn Strip Mine is 8 miles south of Sheridan and produces 3 million tons a year. The Fort Union Monarch and Dietz No. 3 beds coalesce at the Big Horn Mine to form a bed 44 feet thick which is being mined together with the overlying 12-foot thick Dietz No. 2 bed. At least three other mines have been proposed for the Sheridan Coal Field; additionally, Texaco, Inc., has tentative plans for a coal gasification project on the Lake De Smet bed in the Buffalo Field.

4.2.2.1 The Wasatch Coalbeds

The total number of coalbeds in the Wasatch Formation is difficult to determine, because the beds split, coalesce, and are sometimes discontinuous, with beds pinching out and new beds appearing. The coals are generally subbituminous C or in the upper lignite range. Much of the Wasatch coals are under less than 200 feet of overburden, although some may be appreciably deeper. Maximum thickness of the Wasatch Formation is 1500 feet in the Buffalo-Lake De Smet area.

Monument Peak bed. Monument Peak is stratigraphically the highest of the thick coalbeds in the region. It is about 800 feet above the base of the Wasatch Formation, and is 10 to 20 feet thick where it is present north of Lake De Smet in the Buffalo Coal Field (Figure 4-12).

Walters, Healy, Cameron, Murray and Ucross beds. The next five stratigraphically lower major coalbeds of the Buffalo Coal Field--the Walters, Healy, Cameron, Murray, and Ucross--are thought by Obernyer (1978) to be the eastward splits of the Lake De Smet coalbed (Figures 4-12 and 4-14). The Walters bed is 150 to 175 feet below Monument Peak. It is tentatively correlated by Culbertson and Mapel (1976) with the Ulm No. 1 bed in the Sheridan Field. These beds are extensively burned over most of the area, but are 14 to 52 feet thick where they remain, and are split by many small partings of shale. Obernyer (1979, p. 63) has identified the Walters as the uppermost coalbed correlatable with the Lake De Smet bed to the west. The Healy coalbed is 6 to 200 feet below the Walter and Ulm 1. It ranges from 7 to 30 feet in thickness, although the Lake De Smet bed, which is also called the Healy bed in some reports, is locally up to 220 feet thick in the Lake De Smet area. The upper portion of the Healy bed is extensively burned. The Shuman and Timar coalbeds are local and discontinuous. The Shuman contains as much as 9 feet of coal about 10 miles northeast of Buffalo. The Timar bed contains as much as 8 feet of coal at a location a few miles southeast of Buffalo. The Cameron zone is 90-130 feet below the Healy bed, and is composed of two coalbeds. The upper one is 4 feet thick at several places and as much as 7.5 feet thick north of Lake De Smet. The lower Cameron bed consists of one or more lenticular beds of coal 3 to 35 feet below the upper bed. Coal is as much as 19 feet thick in this zone. The Dry Creek bed is a local lens of coal as much as 9 feet thick about 8 miles east of Buffalo. Elsewhere, this stratigraphic interval is carbonaceous shale with thin seams of coal. The Murray bed is 180 to 200 feet below the Healy. Coal in the Murray bed is 4 to 10 feet thick, and split by 1 to 6 feet of shale. The Murray coalbed grades laterally into carbonaceous shale.

The Ucross bed is 80 to 110 feet below the Murray bed. It extends from the Buffalo Field as far south as the northern part of the Sussex Field, and is the lowest persistent coalbed in the Wasatch Formation in that area. In the area north of Lake De Smet, it consists of a 40-foot zone of carbonaceous shale containing discontinuous lenses of coal at several horizons. The bed contains as much as 23 feet of coal in several benches near Box Elder Creek. Culbertson and Mapel (1976) have correlated the Ucross with the PK bed in the Sheridan Field. The PK bed is named for the PK Ranch in Wyarno quadrangle and averages 4 to 18 feet in thickness. The PK bed is locally split into three benches in an interval about 30 feet thick. The main coalbed in the PK zone has been burned along most of its outcrop. Local beds of this same stratigraphic interval (Ulm - PK) in the Sheridan Coal Field include the Upton Gulch, Dow and Arkansas beds (Figure 4-15). The Upton Gulch bed is a local lens of coal as much as 8 feet thick, 10 to 50 feet below the Ulm No. 2 bed, about 20 miles east of the town of Sheridan. The Dow bed is locally up to 10 feet thick in a small area 10 to 15 miles southeast of Sheridan. The Arkansas bed is a 10- to 50-foot zone of carbonaceous shale containing several beds and seams of coal, 2 to 10 feet thick. It is named for the Arkansas Creek in the Jones Draw quadrangle. The coals in this zone have a maximum combined thickness of 15.3 feet, about 20 miles southeast of Sheridan.

Lake De Smet bed. The Lake De Smet bed (Figure 4-14) is thought to be the thickest coalbed in the U.S. and second thickest in the world (Texaco press release, 1975; Obernyer, 1978). It is a linear bed, parallel to and near the Bighorn Mountains in the Lake De Smet area. It is 15 miles long, 0.5 to 2 miles wide and 70 to 220 feet thick. Many thin lenticular partings of sandstone and shale occur in the coal, and become more abundant to the west. The western boundary of the coal is relatively sharp; however, to the east the Lake De Smet bed splits into the five coalbeds previously discussed. The partings between these beds, which average a few feet to over 200 feet in thickness develop to their average thickness in a distance of only 20 to 500 feet. The environment of deposition of the Lake De Smet bed is described in more detail by Obernyer (1978, 1979). Obernyer (1978) states that the coalbed's orientation parallel to and near the Bighorn Uplift, and its great thickness in a region otherwise characterized by abundant high energy input during the sedimentation process, may have been controlled by a basement fault, active during Eocene time. Obernyer also has computed that based on an average accumulation of peat of 0.5 feet per century, the life span of the Lake De Smet coal swamp was 100,000 to 200,000 years.

Lake De Smet occupies a basin thought to have formed by the partial burning of the Lake De Smet coalbed. The lake basin is three miles long, one mile wide and 60 feet deep.

Bar N, Burgess, Heppner, and Wyarno coal zones. Four small coal zones occur near the base of the Wasatch Formation in the Sheridan Coal Field and have been described by Culbertson and Mapel (1976). They are the Bar N, Burgess, Heppner, and Wyarno (Figure 4-13 and 4-15). The Bar N zone is named for the Bar N Draw in the Bar N Quadrangle and consists of two to three beds in a zone 30 to 50 feet thick. The maximum combined thickness of coal is 11.9 feet and occurs in an area about 15 miles northwest of the town of Sheridan. The Bar N coal zone is persistent over most of the area north and west of Sheridan in the Sheridan Coal Field. The Burgess zone is named for the Burgess Ranch in Wyarno and Bar N Draw quadrangles and contains two beds about 5 to 8 miles west of Sheridan. The two beds are locally over 5 feet thick and are separated by 15 to 35 feet of shale. The Heppner bed is a 4 to 6 foot thick coalbed in a small area about 6 to 10 miles west and northwest of Sheridan. It is named for Heppner Draw in the Bar N Draw quadrangle. The Wyarno coal zone is about 650 feet above the base of the Wasatch at the Wyarno Post Office from which it gets its name. It is the lowest persistent coalbed in the Wasatch Formation in the region, and consists of 30 feet of carbonaceous shale, with interbedded coal as much as 10.5 feet thick. All four of these coal zones thin and pinch out southeastward from the Sheridan area.

#### 4.2.2.2 The Fort Union Coalbeds

The coalbeds of the Fort Union Formation are deeply buried in the Buffalo and Barber Coal Fields and have not been individually identified in these fields. A few small beds near the top of the Fort Union are identified in the Sussex Field to the south, where they are designated by the letters "A" through "H" (Figure 4-12). These are thought to occur in the stratigraphic interval between the Roland and Anderson coalbeds, although they have not been correlated positively. In the northern part of the region, in the Sheridan Field, several coalbeds are described by Taff (1909) in the uppermost 2000 feet of the Fort Union Formation. Some of these Fort Union coals are identified in recent maps, coal sections and electric log correlations. A reference list of these maps is included in Appendix C of this report.

Roland bed of Baker (1929). The uppermost Fort Union coal in the Sheridan Field is the Roland bed of Baker (1929). It is persistent over most of the Sheridan Field and ranges from 4 to 29 feet in thickness. It is used in many reports as the boundary between the Fort Union and Wasatch Formations. Figure 4-16 is an electric log correlation section showing the typical response of the Roland and several other Fort Union coalbeds.

Roland bed of Taff (1909). The Roland bed of Taff (1909) which was mined locally by a Mr. Roland, 1 to 2 miles southwest of Monarch is stratigraphically below the Roland bed of Baker (1929). It has been identified in recent mapping in T57-58N, R83-84W, north of Sheridan, and ranges from 2 to 13 feet in thickness. According to Taff (1909), it thins out to the south.

Smith bed. The Smith bed is named for the Smith Mine, one mile southeast of Dietz where it was mined locally in the early 1900s. The Smith bed has been tentatively identified in recent mapping in T56-57N, R80-84W where it is 5 to 19 feet thick, 90 feet below the Roland of Taff (1909) and 110 to 320 feet below the Roland of Baker (1929).

Anderson bed. The Anderson coalbed is tentatively identified in some of the recent mapping of the Sheridan Field in T56-58N, R80-83W where it is 5 to 28 feet thick and 70 to 210 feet below the Smith bed. It is equivalent to the Dietz No. 1 of Taff (1909).

Dietz bed. Three Dietz beds are recognized in the Sheridan region, and were named by Taff (1909) for their proximity to the town of Dietz. Dietz No. 1 of Taff (1909) is equivalent to the Anderson bed; Dietz No. 2 and 3 of Taff (1909) are referred to as Dietz No. 1 and 2 (below the Anderson) in some recent literature (Matson and Pinchock, 1976; Mapel, 1976). Other recent reports and maps (Glass, 1978; and Culbertson and Klett, 1975 a, b) use the combination Anderson-Dietz 2 - Dietz 3. To compound the terminology problem, in some reports the Dietz No. 3 is correlated with the Canyon coalbed (Glass, 1978; Olive, 1957) and in other reports (Matson and Pinchock, 1976; Culbertson, 1975 and Mapel, 1976) the Canyon is shown stratigraphically below the Dietz No. 3. At any rate, as many as four major coalbeds occur within a stratigraphic interval of 300 to 420 feet in the Sheridan Field, and these coalesce eastward to form the thick Wyodak-Anderson coalbed of the Gillette Coal Field. In the Sheridan Field, these separate beds are each 5 to 30 feet thick.

Monarch bed. The Monarch is the thickest coalbed in the Sheridan Field. It averages 5 to 25 feet in thickness and is burned in many places. It is shown to be 47 feet thick in a drill hole near Ranchester, Wyoming (Barnum, 1975) and is as much as 57 feet thick in other places, although it is sometimes combined with the Dietz No. 3 bed (Glass, 1978). The Monarch is correlated with the Wall bed to the east. The Wall bed is shown in recent maps in T56-58N, R80-83W where it ranges from 3 to 30 feet thick and is 100 to 220 feet below the Canyon bed.

Carney bed. The Carney coalbed is described by Taff (1909). It occurs about 100 feet below the Monarch in the towns of Carneyville and Monarch, and it is described as occurring in two benches, 4-10 feet thick and separated by 1 to 4 feet of shale. Coalbeds occurring at this stratigraphic level in recent mapping in the Sheridan Field have not been correlated positively with named beds.

Masters beds. The Masters coal zone occurs about 86 feet below the Carney beds. According to Taff (1909), it consists of two benches, each 6.5 feet thick, and separated by 2 to 3 feet of shale in T57N, R85W. As with the Carney, the coalbeds shown at this stratigraphic interval in recent maps have not been correlated with the named beds.

Roberts bed. The Roberts bed is the lowest coalbed shown in recent quadrangle maps in T56N, R80-82W. The Roberts is about 450 to 600 feet below the top of the Lebo Shale Member of the Fort Union Formation and is 1150 to 1300 feet below the Wall (Monarch) bed. It is 13 to 31 feet thick (Culbertson and Klett, 1975 a, b).

Coal in the Sussex Field. The Sussex Field is south of the Buffalo and Barber Coal Fields. Several Fort Union coalbeds have been identified by Wegemann (1912); they are thought to occupy the approximate stratigraphic interval between the Roland and Anderson beds, although correlation of these beds with those of other fields generally have not been made as no recent geological work has been done in this region. Wegemann (1912) found that the coals of this field crop out in six separate areas, and he concluded that these represent basins of deposition which were not necessarily connected with each other. The "basins" occur along the western margin of the Powder River Basin and are numbered 1 through 6 from north to south.

The northernmost basin ("Basin No. 1") contains several occurrences of coal thought to be in the Lance Formation. They generally range from 15 to 32 inches in thickness although a coalbed is locally 54 inches thick in sec. 10, T37N, R78W. "Basin No. 2" is to the south. It contains a group of Fort Union coals referred to as beds A-H. They range from a few inches to as much as 6.5 feet in thickness. The E bed is the most extensive in this area and ranges from 20 to 46 inches in thickness. Bed F, which is 19 to 36 inches thick, is thought to be equivalent to the F bed in the Dry Cheyenne and Gillette Fields to the east. "Basin No. 3" contains four coalbeds, each averaging 20 to 32 inches in thickness. At one point, the highest bed contains a total of 5.5 feet of clean coal. "Basin No. 4" is the most important, economically. It contains two coalbeds which can be traced over most of the "basin."The lower bed, averaging 11.8 feet in thickness over a distance of 7 to 10 miles, is up to 50 feet thick in places. The bed thins to 18 to 36 inches in the south and is thought to persist at that thickness for another 8 to 9 miles. The upper bed is thinner as well as irregular in thickness. It is generally 9 to 47 inches thick, and broken with numerous shale partings. "Basin No. 5" contains one important bed which is 20 inches thick in most places, and up to 55 inches in four benches at one locality. "Basin No. 6" contains two beds, 100 feet apart. The lower bed is generally 24 to 36 inches thick. At one locality, it is as much as 13 feet thick. The upper bed, generally ranging from a few inches to 45 inches in thickness, is as much as 9 feet thick locally.

### 4.2.3 Northern Coal Fields

The Northern Powder River region includes all of the Montana portion of the Powder River Basin and contains nine coal fields (Figure 4-4). They are the Rosebud, Forsyth, Tullock Creek, Mizpah, Ashland, Coalwood, Birney Broadus, Moorhead and Sheridan Northern Extension. Coal is present in all three members of the Fort Union Formation as well as the overlying Wasatch Formation; however, all of the important coalbeds occur in the Tongue River Member of the Fort Union Formation. A coal-deposit location map, stratigraphic correlation charts and typical analyses for the northern fields are given in Figures 4-17 through 4-21, and Table 4-11. There are six coalbeds that are considered to be the most important in respect to the quality and magnitude of the coal reserves they contain: the Anderson, Dietz, Canyon, Wall, Knobloch and Rosebud. Numerous smaller coalbeds are present locally, but will not be described in detail here. The thickest deposits and best quality coal are found in the Decker area. Four coal mines are presently operating in the northern Powder River Basin area, all of them along the west side of the basin.

The general structural configuration of the northern region of the Powder River Basin in Montana is that of a broad south-westward plunging synclinal fold, the axis of which is generally coincident with the Tongue River Valley (Mapel and Swanson, 1977). Many smaller folds are superimposed on the general basinal structure, and faults with displacements of a few feet to nearly 200 feet are present locally. The faults which affect the upper part of the Fort Union Formation and the basal part of the Wasatch Formation, generally trend northeastward and may extend for several miles.

The steepest dips are associated with the uplift of the Bighorn Mountains on the west margin of the basin. Dips generally are 1 to $4^{0}$ but are reported to be as much as $30^{0}$ E-NE near the southwest corner of the region, adjacent to the Bighorn Uplift. The northwest portion of the region has been influenced by the Big Snowy Uplift resulting in strata dipping gently southward. Between these two uplifts is a southeast trending structural low, in which the rocks have been gently warped and faulted (Baker, 1929; Rogers and Lee, 1923). Rocks along the northern margin of the Powder River Basin have been affected by the Porcupine Uplift which has resulted in several small faults with individual throws of about 60 feet. A structural depression or southeastward-pitching trough separates the Porcupine Uplift on the north from the Bighorn and Big Snowy

Uplifts on the west. The rocks within this depression, which may extend as far south as Ashland, are folded into several small anticlinal and synclinal folds. Nearly all dips are less than $1^{0}$ (Dobbin, 1930; Bass, 1932). The north-central portion of the region is influenced by the Tongue River Syncline, which is a broad northeast plunging syncline, coincident with the Tongue River Valley, dividing the Black Hills Uplift on the east from the Porcupine Dome on the north. Small faults with displacements of 75 feet or less and gentle dips of 1 to $3^{0}$ are associated with the syncline. Steeper dips are present, but are thought to be related to slumping of the beds during deposition (Bass, 1932; Pierce, 1936). A low anticline trends eastward across the central portion of the region, crossing Otter Creek. Dips remain relatively flat (1 to $3^{0}$) throughout most of the center of the area, although local dips of $20^{0}$ may occur in areas of slumping where coalbeds have burned. A few widely spaced west-southwest trending faults occur in the central portion of the area (Warren, 1959; Lewis and Roberts, 1978). Along the eastern margin of the basin, the rocks dip due west as much as 75 feet per mile. Some very small local folds and small northeast trending normal faults with throws of 50 to 200 feet are present in the eastern portion of the region (Bryson and Bass, 1973).

Coal in the northern Powder River Region increases in rank from lignite A in the northeastern part of the region to subbituminous southwestward. The coal is non-coking and non-agglomerating, with low ash and low sulfur contents. It loses moisture and slacks when exposed to air. Chemical analyses for the major coalbeds are summarized in Table 4-11.

#### 4.2.3.1 Coal in the Wasatch Formation

Felix and Arvada beds. The youngest coal-bearing formation in the region is the Wasatch of Eocene age, which is present only in the extreme southern and southwestern area near the Wyoming border. The basal part of the Wasatch is exposed in that area and contains two relatively small coalbeds: the Felix, which is 250 feet above the Roland (the uppermost coalbed in the Fort Union Formation), and the Arvada, which is 75 to 100 feet above the Roland in the Moorhead Coal Field. Thin lenses of coal are reported to occur in the Wasatch Formation in the Northern Extension of the Sheridan Field (Bryson and Bass, 1973; Warren, 1959).

4.2.3.2 Coal in the Fort Union Formation

Roland bed of Baker (1929). The Roland of Baker (1929) is the uppermost coalbed within the Fort Union Formation in this region. It is present in the south-central portion of the area, where it is commonly 5 to 13 feet thick. In many of the older reports on the region, the Roland was considered to mark the contact of the Fort Union with the overlying Wasatch. However, the exact position of the contact is still disputed. About 150 feet below the Roland is the Smith bed.It is present in the southern portion of the region and averages 2 to 3 feet thick.

Anderson bed. The Anderson is stratigraphically the highest of the important coalbeds, and is about 290 to 370 feet below the top of the Roland bed. It ranges from 15 to 80 feet thick and is persistent over most of the southern half of the region. The highest quality coal from the Anderson bed is found at the Decker deposit, where the Anderson combines with the underlying Dietz No. 1 bed to form a seam 50 feet thick. This seam is being mined by the Decker Mining Company at its Decker No. 1 Mine. North and east of the Decker deposit, the quality of the coal decreases. West of the Decker area, the Anderson is combined with the Dietz No. 1 and No. 2 beds to form a seam 80 feet thick, but to the east at the Deer Creek deposit, the three beds are separate, and the Anderson is 20 feet thick. Further east at the Hanging Woman Creek area, the Anderson bed is 15 to 36 feet thick, and in the Moorhead Coal Field it is 14 to 30 feet thick. To the north, at the Poker Jim Lookout deposit, the Anderson is again combined with the Dietz to form a bed 58 feet thick. The Anderson and Dietz No. 1 beds are thought to be equivalent to the Garfield bed in the north and east portions of the region (Matson and Pinchock, 1976; Mapel and Swanson, 1977).

Dietz beds. The Dietz No. 1 and No. 2 beds (Dietz No. 2 and No. 3 of Taff, 1909) are major coalbeds in the southern third of the region, lying as much as 250 feet below the Anderson in places on the east side of the Tongue River. Elsewhere, the two beds may be combined with each other, or the top bed or both beds may be combined with the Anderson. Where separate, the beds are each up to 20 feet thick. The best quality Dietz coal is found at the Decker and Kirby deposits, and is being mined along with the Anderson bed at the Decker No. 1 mine. The quality decreases to the east of these deposits (Matson and Pinchock, 1976).

Canyon bed. The Canyon is one of the most widespread of important coalbeds in the region. It is 80 to 200 feet below the Dietz No. 2 bed and is up to 30 feet thick. As with the overlying coals, the quality of the Canyon coalbed is best in the Decker and Kirby areas, although the largest reserves are present in the West Moorhead and Diamond Butte deposits. At these two deposits, the Canyon bed averages 17 to 24 feet thick and 16 to 25 feet thick, respectively. The Canyon bed is not being mined at the present time (Matson and Pinchock, 1976).

Ferry and Cook beds. Two small coalbeds, the Ferry and the Cook, are identified between the Canyon and underlying Wall coalbeds. The Ferry coalbed consists of discontinuous lenses of coal which are 6 to 17 feet thick at the Three Mile Buttes deposit and 24 feet thick at the Home Creek Butte deposit, where it occurs 76 feet below the Canyon coalbed. The Cook coalbed forms two benches in the Birney-Broadus Field. The upper bench ranges from 0 to 19 feet thick and the lower bench from 5 to 14 feet thick. The parting between them is 12 to 75 feet thick (Matson and Blumer, 1973).

Wall bed. The Wall coalbed is an important bed, lying about 180 to 230 feet below the Canyon bed. It is thickest and most persistent over the southwestern portion of the region and contains some of the highest rank coals in the region. The Wall bed is 50 to 60 feet thick at the Canyon Creek and Kirby deposits. East of the Tongue River-Hanging Woman Creek area, the Wall seems to split into two or more beds.

Several smaller coalbeds are found between the Wall and Knobloch beds. They are, stratigraphically from upper to lower, the Elk, Pawnee, Dunning, E, X, C and D, Brewster-Arnold, Cache, T, Sawyer, and A coalbeds. The Elk, Pawnee, Dunning, Brewster-Arnold and T beds are all found in the Birney-Broadus Coal Field. The Cache and T are in the Moorhead Coal Field, and the E, X, C and D, Sawyer and A beds are in the Ashland Coal Field. Where mapped, these beds are 7 to 36 feet thick (Matson and Blumer, 1973; Mapel and Swanson, 1977).

Knobloch bed. The Knobloch is an important coalbed, 350 to 400 feet below the Wall bed, and is widespread over most of the region. The

Knobloch reaches a maximum thickness of 66 feet in the Otter Creek and Ashland deposits, and splits into three benches a short distance south of Ashland. The highest quality coal in the Knobloch is in the Poker Jim Creek-O'Dell Creek deposit. More strippable reserves of coal are present in the Knobloch than in any other mapped unit in the Tongue River Member in Montana (Matson and Pinchock, 1976; Matson and Blumer, 1973).

One small coalbed, the Lay Creek bed, occurs 30 to 88 feet below the Knobloch in the Mizpah Coal Field where it is 2 to 6 feet thick. It is irregular both in thickness and quality, and may actually be a split off the Knobloch coalbed (Matson and Blumer, 1973).

Rosebud bed. The Rosebud is stratigraphically the lowest of the important coalbeds in the region. It is 60 to 80 feet below the Knobloch and 350 feet above the base of the Tongue River Member in the northwestern part of the region. The Rosebud bed is being mined at the Colstrip deposit by Western Energy Company, at the Big Sky Mine by Peabody Coal Company, and at Sarpy Creek by Westmoreland Coal Company, where it is 15 to 35 feet thick. Its equivalent in the Tullock Creek Coal Field in the northwestern corner of the area is Bed Q. The coal thins southward and eastward. East of the Tongue River, the Flowers-Goodale and Broadus beds are at the approximate stratigraphic level of the Rosebud. The Broadus in the Broadus deposit is 5 to 26 feet thick. It has been correlated with the 9- to 12-foot thick Flowers-Goodale bed, 50 miles to the northwest of Broadus (Matson and Blumer, 1973; Matson and Pinchock, 1976; Mapel and Swanson, 1977).

Terret and Dominy beds. The Terret and Dominy beds occur in the basal portion of the Tongue River Formation. The Terret bed is 45 feet below the Flowers-Goodale bed in the Beaver Creek-Liscom Creek deposit, where it is 6 to 10 feet thick. The Dominy coalbed is in the Miles City Coal Field immediately north of the basin boundary. It consists of two benches, the upper averaging 19 feet thick and the lower 6 feet thick (Matson and Pinchock, 1976).

Coal also occurs in the Tullock and Lebo Shale Members of the Fort Union. Generally these beds are less than 3 feet thick, are lenticular, and contain thin partings of shale. The Big Dirty coalbed, at the base of the Lebo Shale Member, is as much as 11 feet thick in places within the

Forsyth Field. The Lance Formation and older rocks in the northern region of the Powder River Basin are not considered coal-bearing formations.

### 4.2.4 Coal Fields of Southern Powder River Basin

Three coal fields comprise the southern portion of Powder River Basin--the Lost Spring, Dry Cheyenne and Glenrock Fields (Figure 4-4). The Dave Johnston Mine, the only operating coal mine in the region at present, is 14 miles north of Glenrock, in the Glenrock Field. Coal-bearing rocks of this area include the Fort Union and Wasatch Formations of Tertiary age, and the marine Lance and Mesaverde Formations of Cretaceous age. The coal-bearing rocks dip basinward, 15 to 25$^{o}$ around the periphery of the basin, and flatten to 1 to 5$^{o}$ within a few miles of the basin margin. Most of the coal zones have not been correlated positively with those of other fields to the north, as there has been very little recent geologic work performed in the area.

Coalbeds of the Dry Cheyenne Field. Dry Cheyenne (Figure 4-4) is a small coal field covering 290 square miles, south of the Gillette and east of the Sussex Fields. Exposed rocks in the field include the Tongue River Member of the Fort Union, and the overlying Wasatch Formation, which generally dip 2 to 4$^{o}$ west toward the axis of the Powder River Basin. Three small synclinal flexures are superimposed on the basin structure. The Dry Fork of the Cheyenne River in the center of the field is coincident with the axis of a shallow syncline. As indicated at their outcrop, the rocks dip about 75 feet per mile toward the river near the junction with Willow Creek. In the southwest corner of the field, the rocks again form a broad open syncline with shallow dips. The axis trends SE-NW and plunges to the north. In the northwest corner of the field, the rocks form a northward pitching syncline with dips of about 100 feet per mile on either limb (Wegemann, et al, 1928).

Three coalbeds are exposed in the field; none are mined at present. The lowest bed, Bed H in the Fort Union Formation, ranges from less than 1 foot to 4.3 feet thick. It is thought to be equivalent to the Roland, or Bed D, of the Gillette Field. Bed G is 220 feet above H in the Wasatch Formation and averages two feet thick. It is thought to be equivalent to the Lower Bed of the Sussex Field. Bed F, 160 feet above G, is lenticular and ranges in thickness from a minimum of one foot to a maximum of 11.5

feet. Bed F is possibly equivalent to the Upper Bed of the Sussex Field and to Bed C of the Gillette Field. All of the coals in the Dry Cheyenne Field are subbituminous (Wegemann, et al, 1928; Berryhill, et al, 1950). Analyses of coal samples are shown in Table 4-12.

Coalbeds of the Lost Spring Field. The Lost Spring Coal Field covers an area of 1,060 square miles. It is south of the Gillette Field and east of the Dry Cheyenne Field, and forms part of the southern and eastern margins of the Powder River Basin. Steep dips occur along these margins but flatten to become nearly horizontal about one mile into the basin. The lower coalbeds dip as much as 15°N near Douglas and 25°SW near the eastern edge of the field. At the northeast corner of the field, the rocks dip only slightly to the west and strike nearly N-S. A slight anticlinal structure with local dips up to 5° is present near the junction of the two forks of Twentymile Creek, about 10 miles northwest of the town of Lost Spring (Winchester, 1912).

The coalbeds of the Lost Spring Coal Field are within the Fort Union Formation, and form two distinct coal-bearing groups, separated by 600 to 700 feet of strata. The beds of the lower group crop out along the south and western margins of the basin. They are all less than 6 feet thick and lenticular. Although there are no active mines producing from these beds at present, several mines have operated in the past in an area about 10 miles long, W-NW of the town of Lost Spring. Beds of the upper coal zone crop out in the northern part of the field. The coals of this group are thicker and more persistent than the coals of the lower group. The beds are designated by letters beginning with the lowest (in contrast with most areas of the Powder River Basin). Bed E is the highest and can possibly be correlated with J Bed of the Gillette Field to the north. It has a maximum thickness of 9.6 feet. Bed B is lower and is thought to be equivalent to Bed K of the Gillette Field. Coals of the Lost Spring Field are subbituminous in rank. They are bright, black and hard when fresh, but crumble rapidly when exposed to dry atmosphere for a short time (Berryhill, et al, 1950; Winchester, 1912).

Coalbeds of the Glenrock Field. The Glenrock Coal Field (Figure 4-4) covers an area of 1,500 square miles in Converse and Natrona Counties. South of the Dry Cheyenne and Sussex Fields, it is in the southwest corner of the Powder River Basin. Four coal zones are present in the 5800 feet of strata exposed in the field. One mine, the Dave Johnston Strip Mine, is operating in the area. The oldest mines in the field, now closed, opened near Douglas in 1883.

The rocks of the Glenrock Coal Field form part of the southern edge of the Powder River Basin where they are folded and faulted near the Laramie Range. Dips in the Lance Formation range up to $35^{\circ}$ N-NE just northeast of Glenrock, and up to $70^{\circ}$ NE near the town of Cole Creek. The Tullock Member of the Fort Union dips as much as $28^{\circ}$ NE at a location about midway between Glenrock and Douglas. Elsewhere dips are variable and decrease away from the basin edge. Near the Dave Johnston Mine, the rocks dip 2 to $7^{\circ}$ E-NE (Denson and Horn, 1975).

The lowermost coal zones in the Glenrock Field are the A and B beds in the Cretaceous Mesaverde Formation (Figure 4-22). These coals are 1.8 to 3 feet thick and have been mined only locally (Glass, 1978; Shaw, 1909). Though subbituminous in rank, they are described as blacker, cleaner, more brittle and more lustrous than the overlying coals of the Lance and Fort Union Formations (Shaw, 1909).

The Glenrock-Big Muddy coal zone is 1400 feet above the "A" Bed. It contains two lenticular beds of coal in the basal 200-300 feet of the Lance Formation. This coal-bearing zone is about 15 miles in length and extends from just east of Glenrock to just northeast of Casper. The coalbeds near Glenrock are up to 6.8 feet thick, and less than 5 feet thick near the towns of Big Muddy and Casper. These coals are subbituminous in rank although of slightly better quality than the younger Fort Union coals (Glass, 1978; Berryhill, et al, 1950; Shaw, 1909).

The Douglas-Inez coal zone of the Fort Union Formation is 2500 feet above the base of the Glenrock-Big Muddy zone. The coal-bearing zone is 1000 feet thick and contains two beds, each over 5 feet thick and lenticular, and several smaller beds which are present locally. The two thicker beds are referred to in the more recent literature as the Badger and School beds, and both are thought to be near the top of the Fort Union, although Denson, Dover and Osmonson (1978) have placed them near the base of the Wasatch Formation. Coal in the School bed is 110 to 180 feet below the

Badger, averages 35 feet in thickness, and is subbituminous in rank. It thins to 22 feet thick toward the north, and the quality deteriorates to the south with increasing amounts of shaley partings. The School seam possibly is the equivalent of the Smith coal of surrounding areas. Overlying the School bed is the Badger coal seam, which Duell (1969) tentatively correlates with the Roland bed of the Powder River, Gillette and Sheridan Coal Fields. The Badger, 17 to 20 feet thick, is subbituminous in rank, and improves slightly in quality toward the north with the absence of shaley partings. The coal yields to weathering and deteriorates on exposure. The Badger seam is being strip mined along a 12-mile length at the Dave Johnston Mine. Stripping began in 1958, and in 1970 the mine was the nation's largest producer with 1.8 million short tons. The mine is currently producing 3.1 million tons/year, all of which is being shipped 14 miles to the Dave Johnston Power Plant (Wyoming Dept. of Economic Planning & Development, 1978; Duell, 1969; Shaw, 1909; Berryhill, et al, 1950; Lane, et al, 1972). Analyses of coal samples from the Glenrock Coal Field are given in Tables 4-13 and 4-14. Typical gamma ray logs are shown in Figure 4-23.

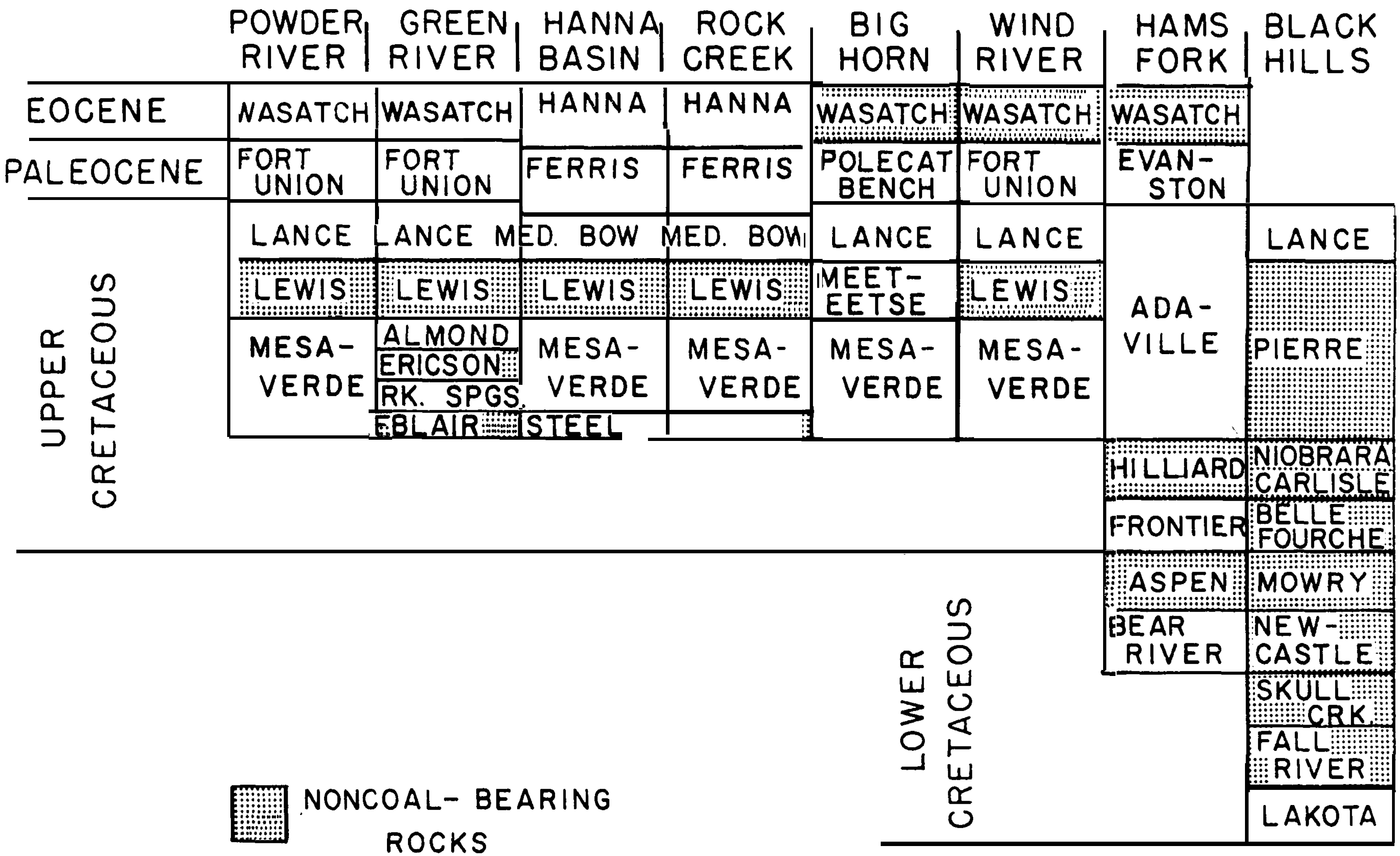



Figure 4-l Major Coal-Bearing Formations of Powder River Basin and Correlation to Other Areas in Wyoming and the Black Hills (Glass, 1978).

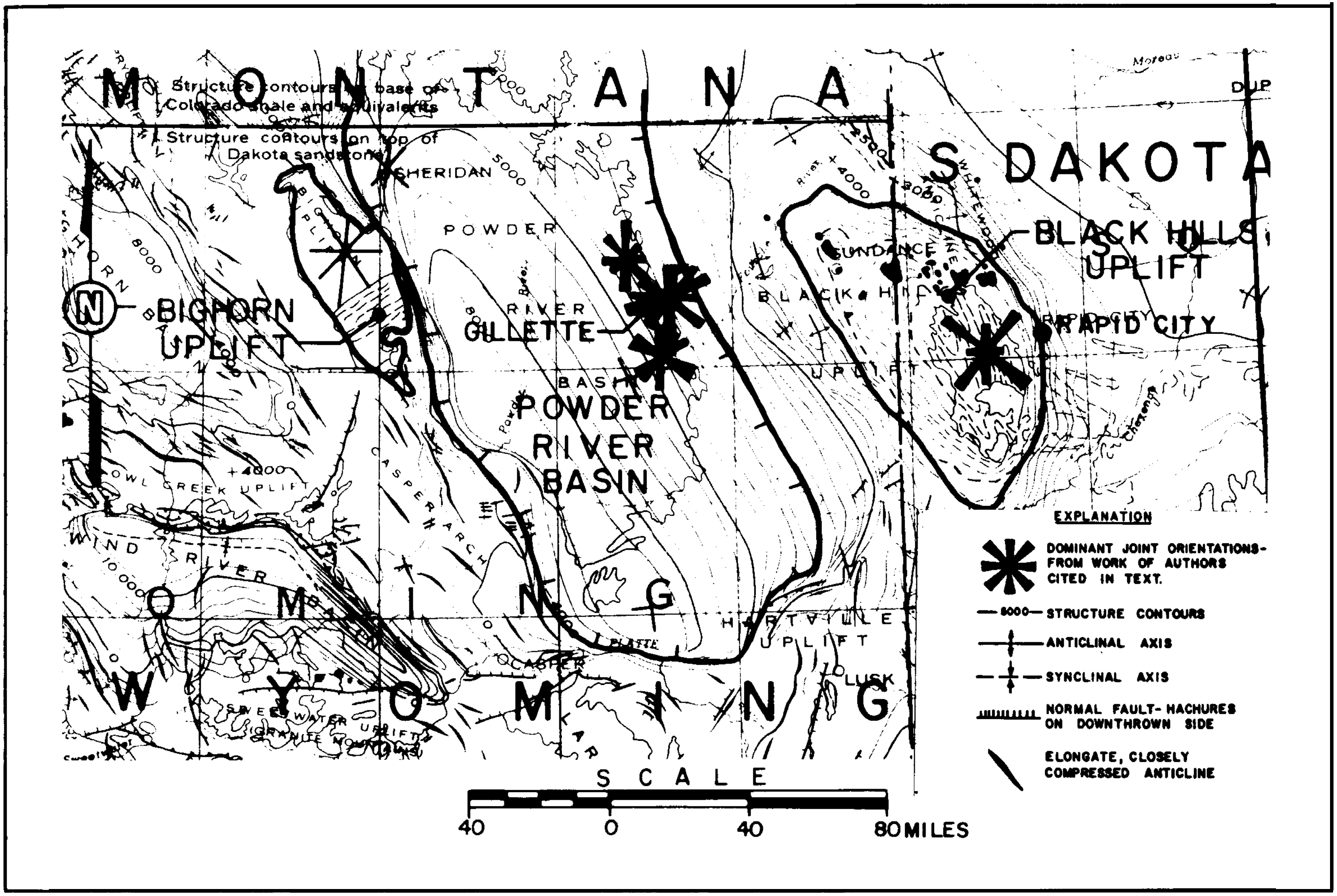



**Figure 4-2** Dominant Joint Orientations of Rocks in the Powder River Basin and Surrounding Areas (Henkle, Muhm and DeBuyl, 1978).

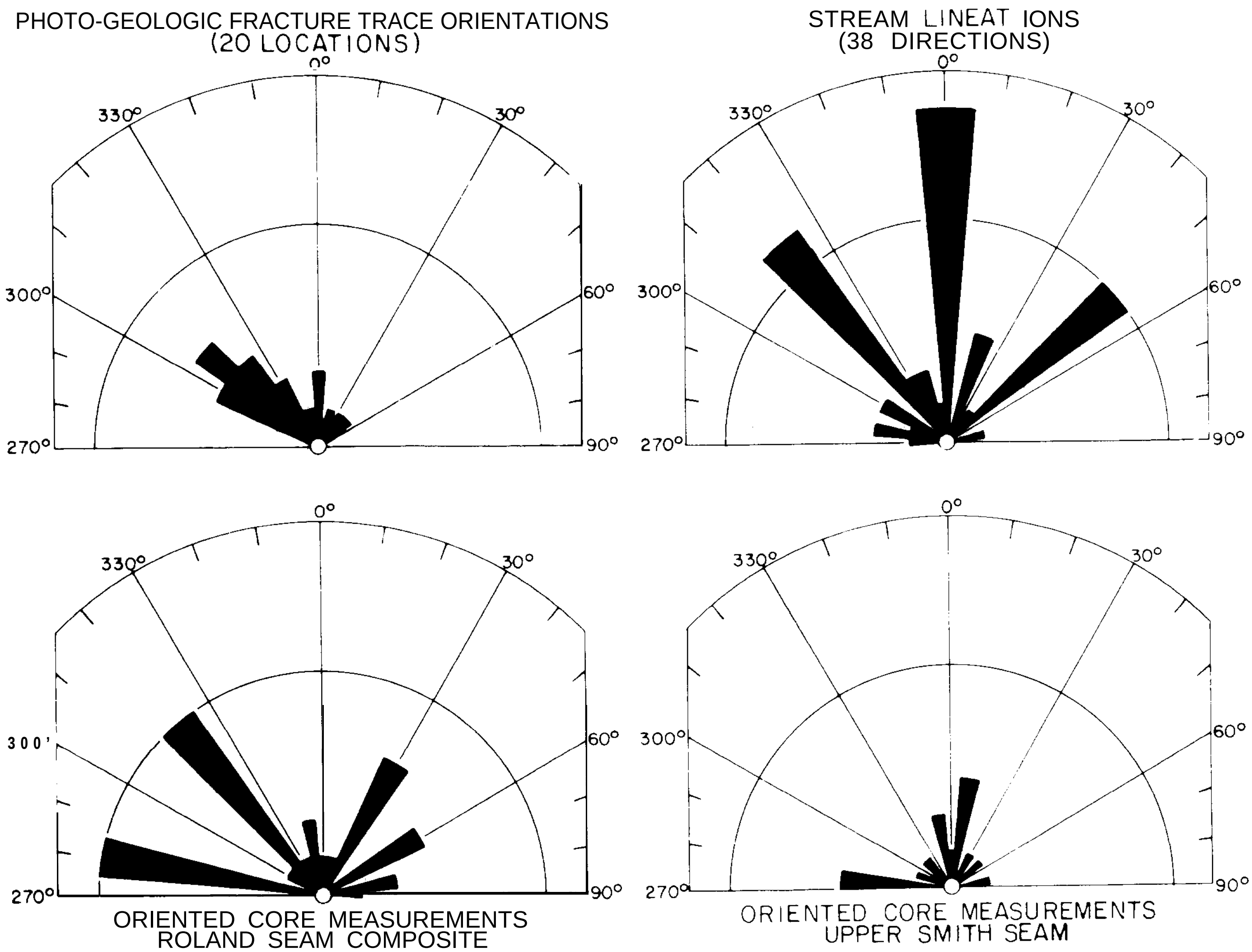



Figure 4-3 Dominant Lineations and Fracture Orientations as Determined by Henkle, Muhm, and DeBuyl (1978) in Their Study Area Near Gillette, Wyoming.

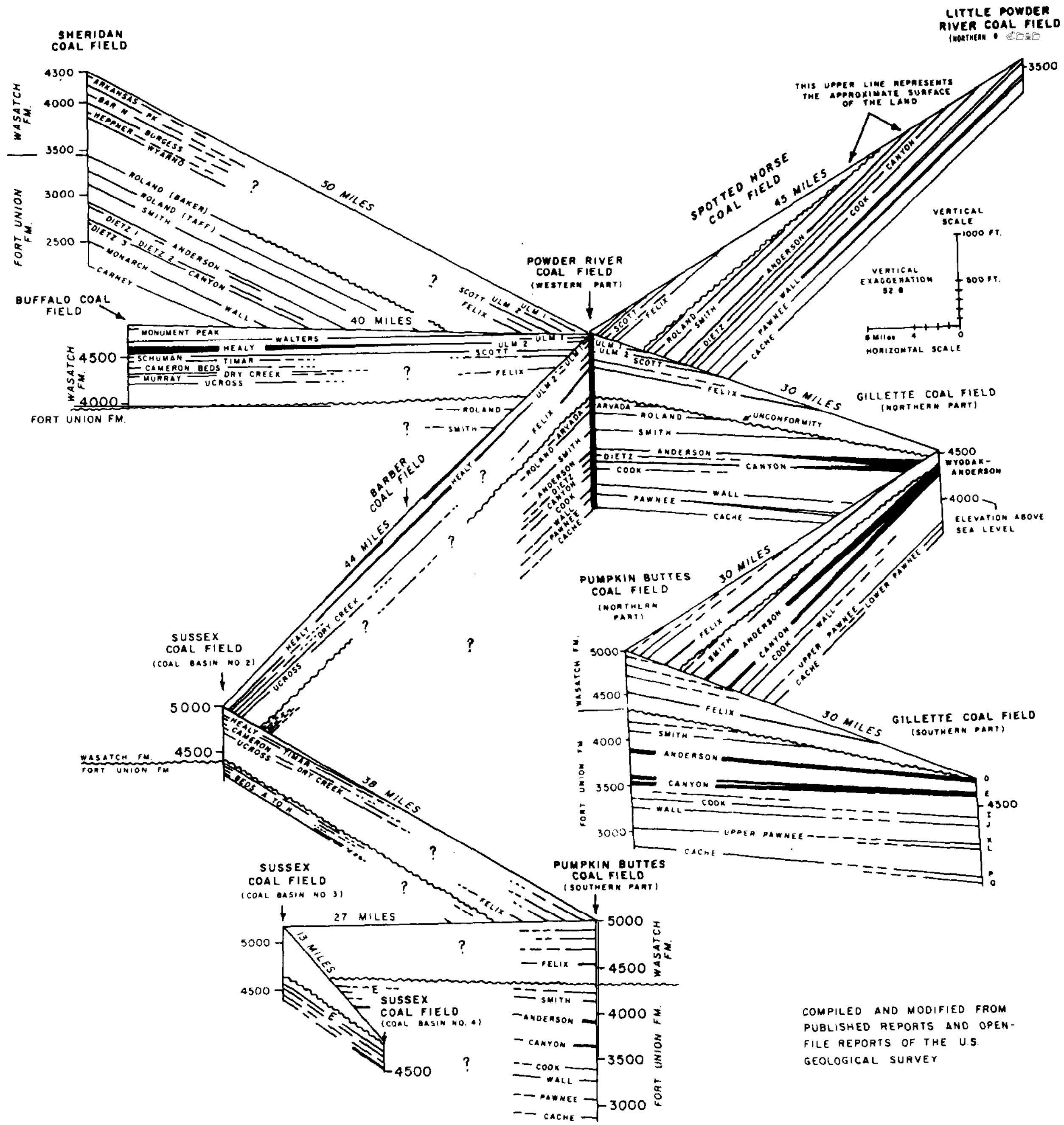



Figure 4-5 Fence Diagram Showing Stratigraphic Correlations of Coalbeds Between Major Eastern and Western Powder River Basin Coal Fields (After Glass, 1976).

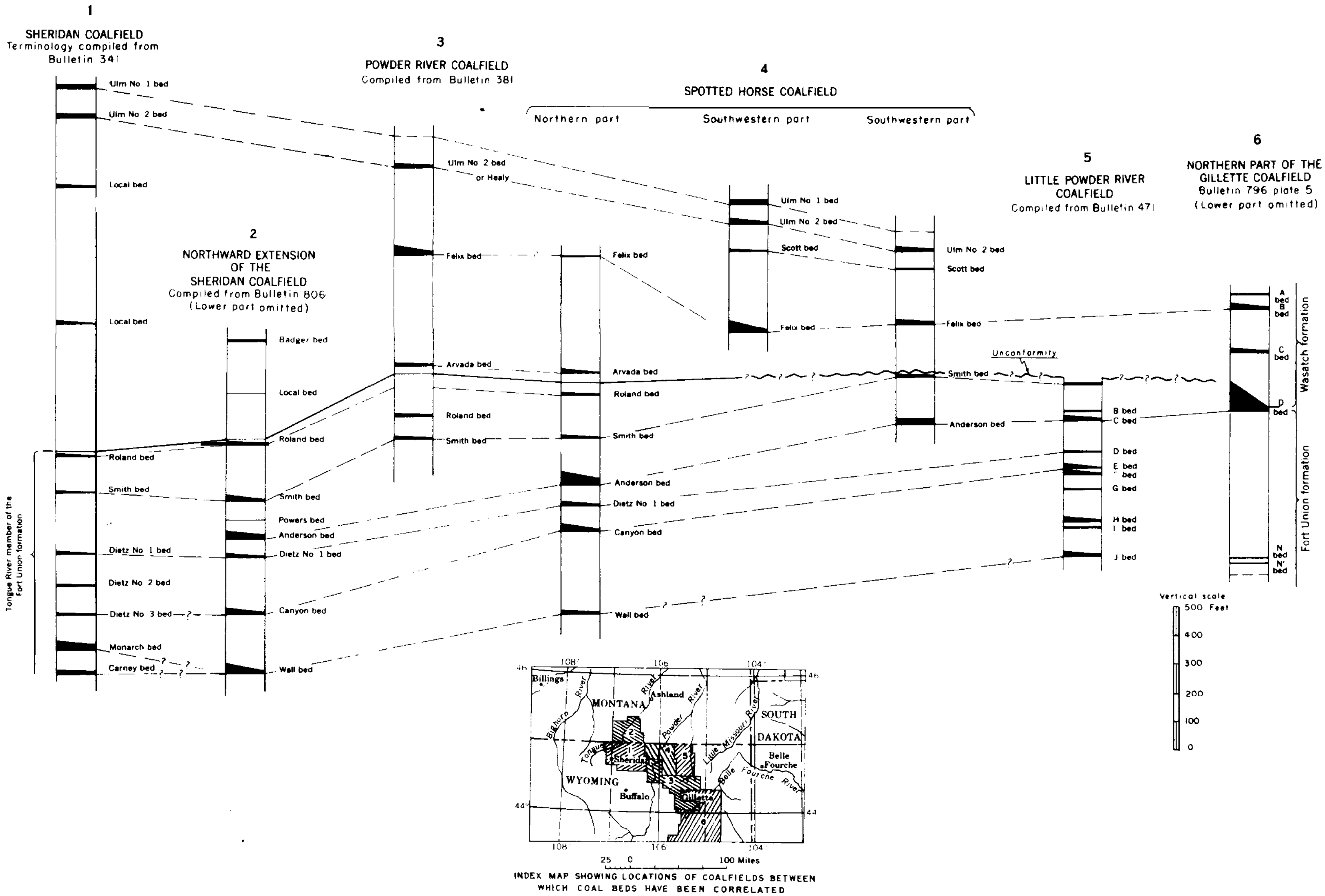



**Figure 4-6** Chart Correlating **Coalbeds** from the Gillette Coal **Field, Wyoming**, to the Northern Extension of the Sheridan Coal Field, Montana (Olive, 1957).

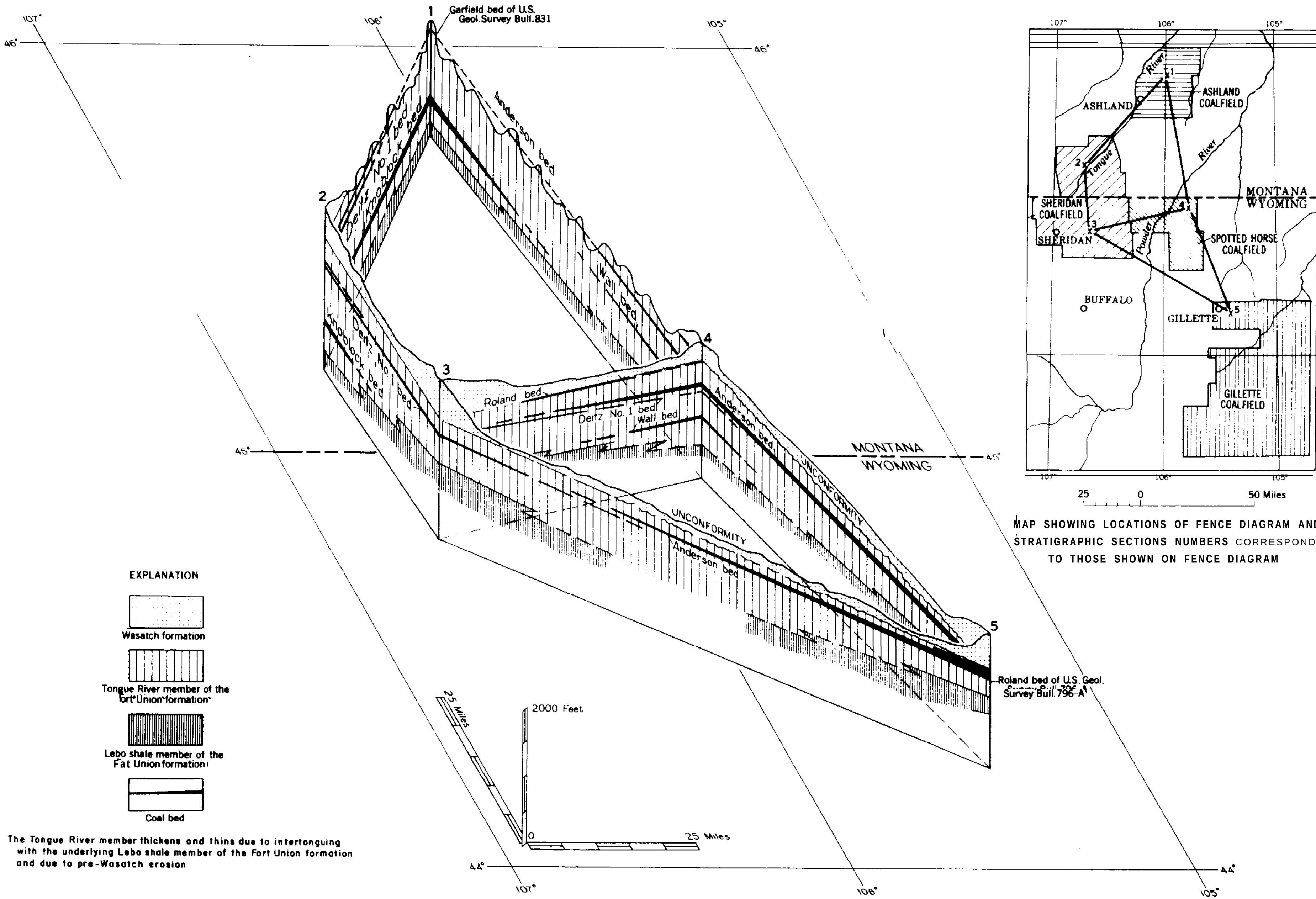
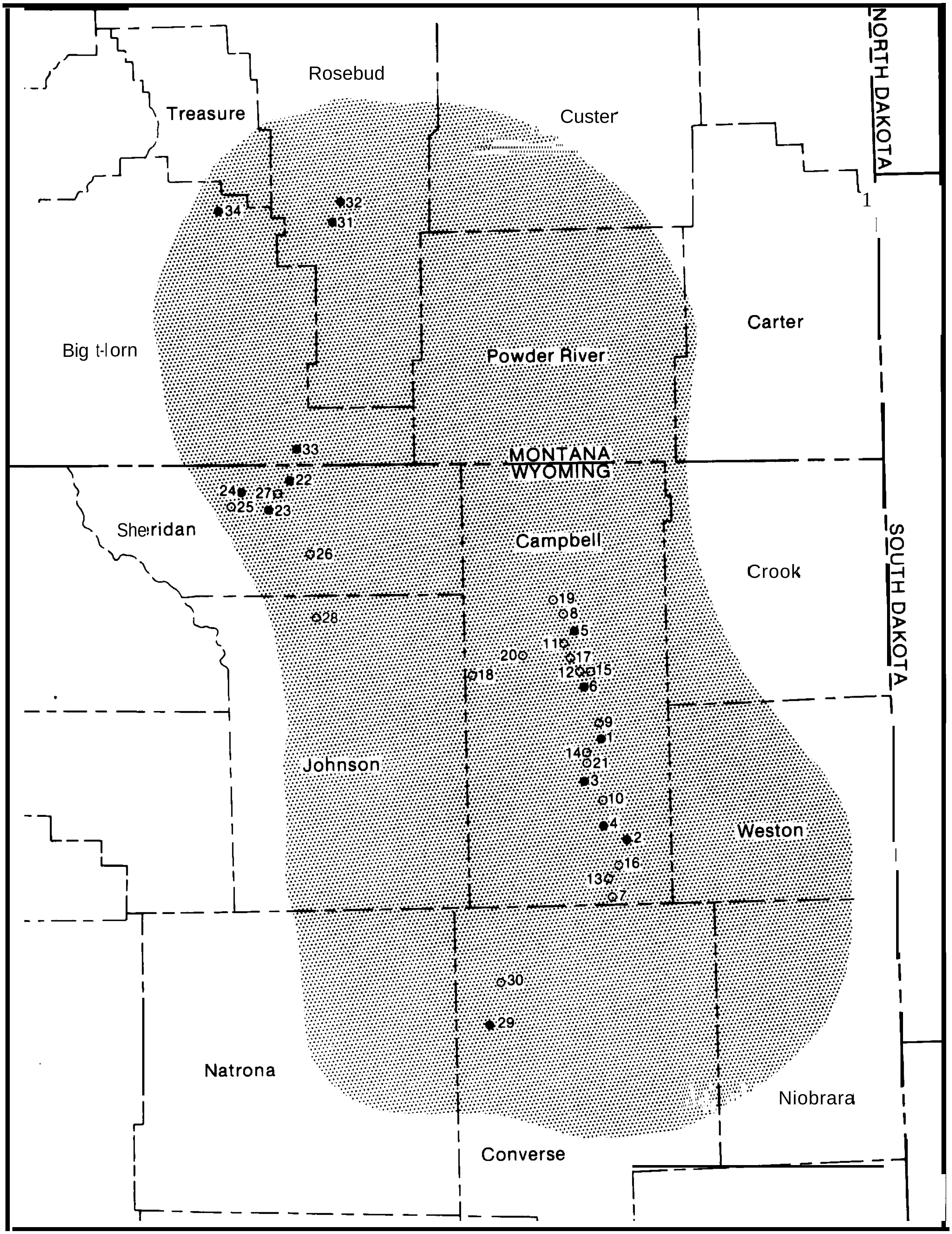



**Figure 4-7** Fence Diagram Correlating Coalbeds of Tongue River Member of Fort Union Formation in Northern Wyoming and Southern Montana (Olive, 1957).




• Active Mines o Proposed Mines

**Figure 4-8** Location of Coal Mines in the Powder River Basin Source: Mapel and Swanson, 1977; Wyoming Department of Economic Planning and Development, 1978.

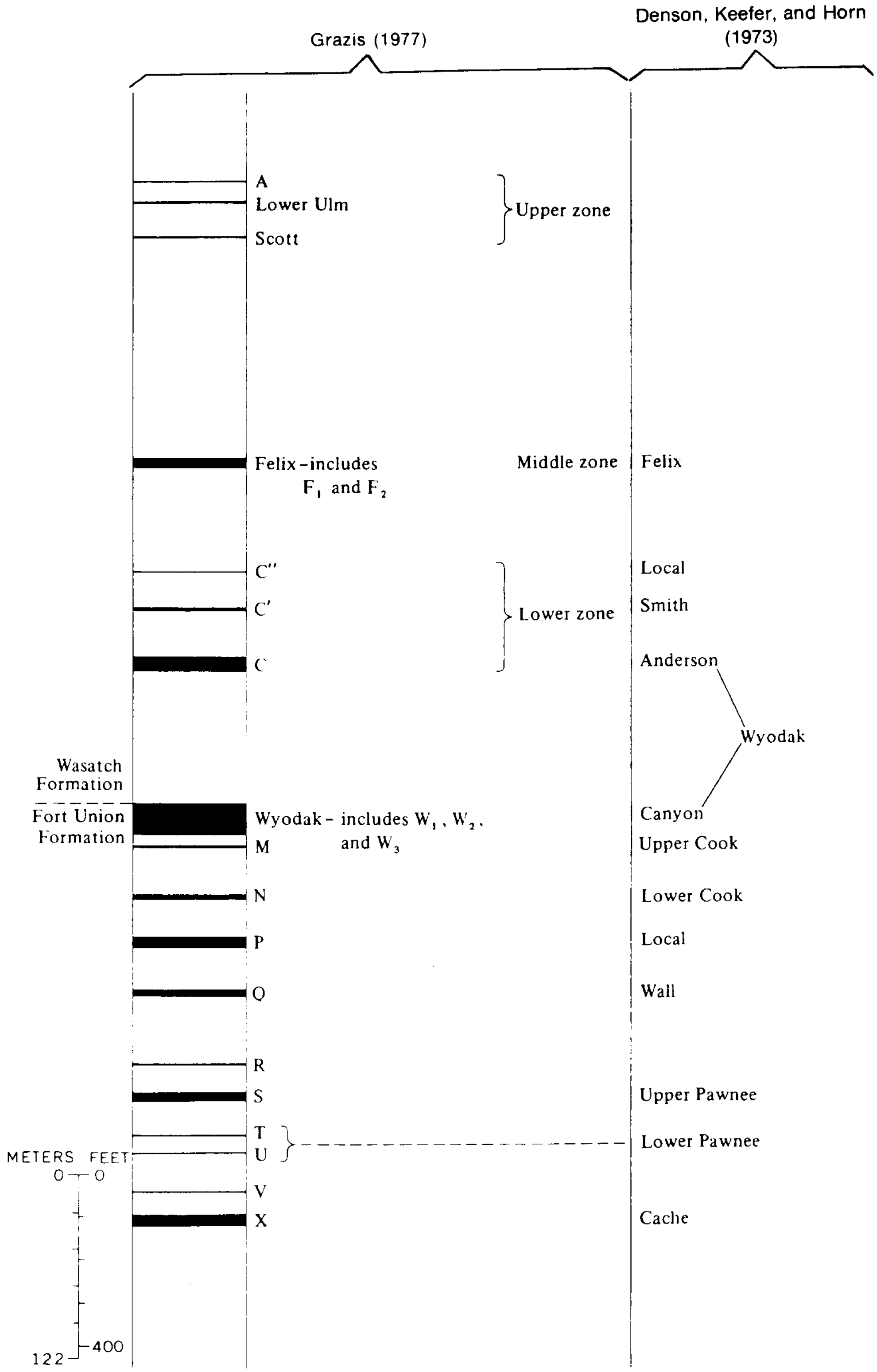
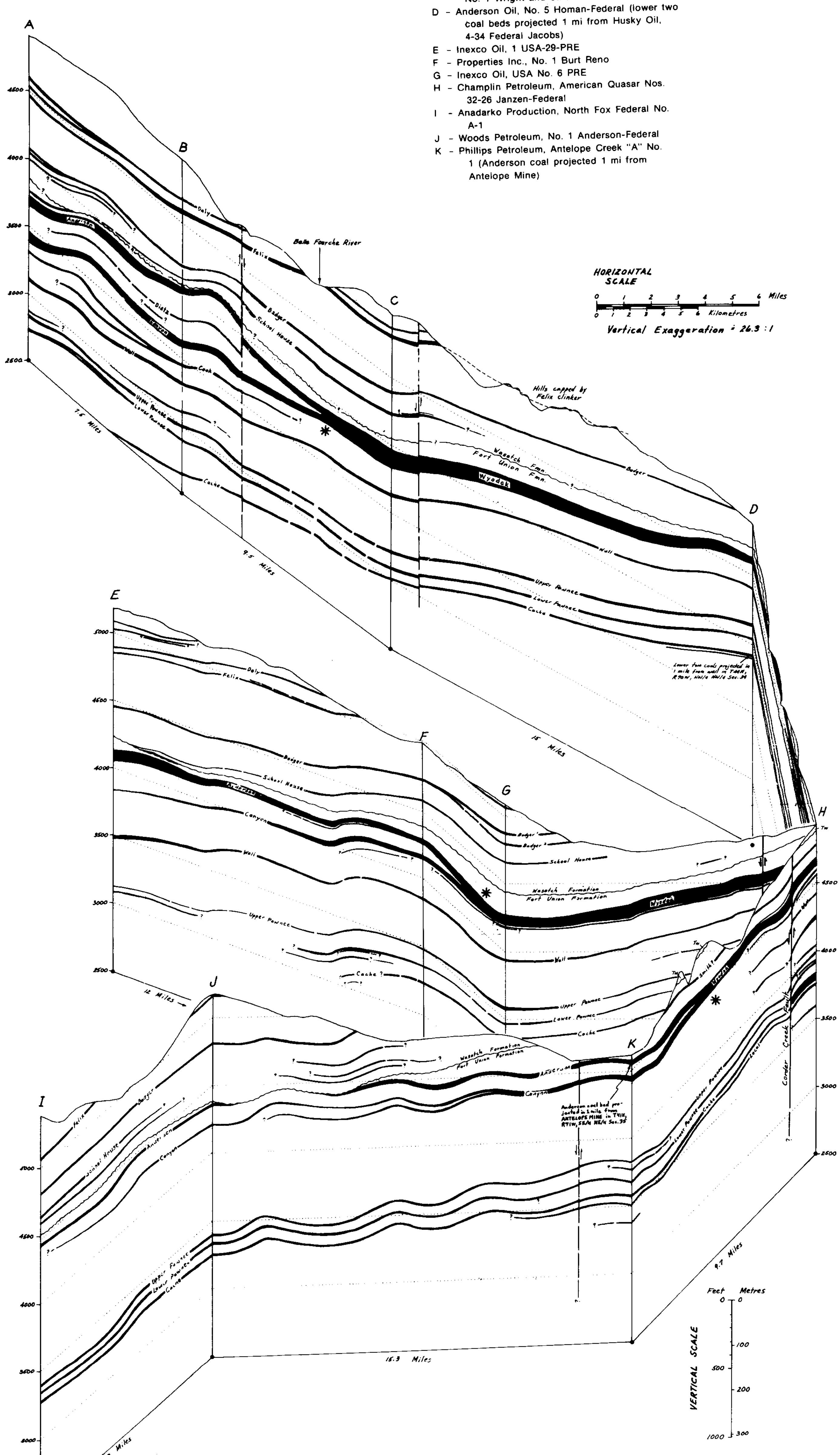



**Figure 4-9** Stratigraphic Columns of Fort Union and Wasatch Coalbeds in Campbell County as Compiled from Drill-Hole Geophysical Logs by the U.S. Geological Survey. Difficulties in Correlation of Beds and Placement of the Fort Union-Wasatch Contact is Demonstrated.

Wells and mine used for primary control in constructing fence diagram.

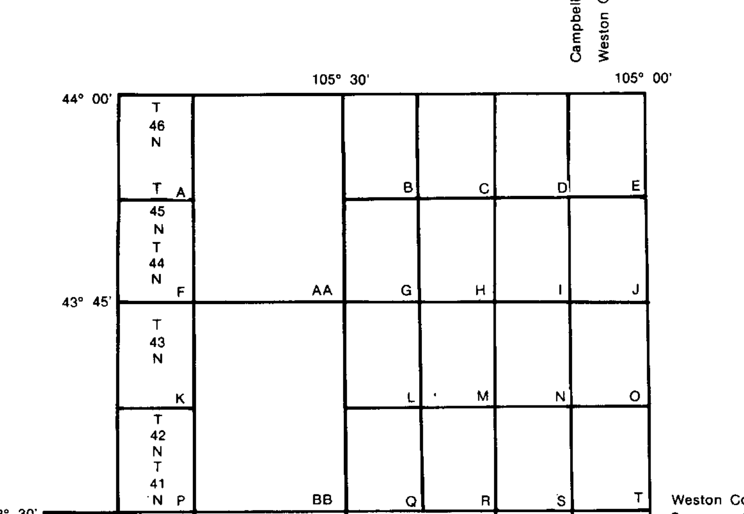
A - Davis Oil, No. 1 Craig State
B - Davis Oil, No. 1 Equity-Federal
C - International Nuclear and King Resources, No. 1 Wright and others
D - Anderson Oil, No. 5 Homan-Federal (lower two coal beds projected 1 mi from Husky Oil, 4-34 Federal Jacobs)
E - Inexco Oil, 1 USA-29-PRE
F - Properties Inc., No. 1 Burt Reno
G - Inexco Oil, USA No. 6 PRE
H - Champlin Petroleum, American Quasar Nos. 32-26 Janzen-Federal
I - Anadarko Production, North Fox Federal No. A-1
J - Woods Petroleum, No. 1 Anderson-Federal
K - Phillips Petroleum, Antelope Creek "A" No. 1 (Anderson coal projected 1 mi from Antelope Mine)




INDEX TO TOPOGRAPHIC QUADRANGLE MAPS IN THE RENO JUNCTION-ANTELOPE CREEK AREA

7 ½-Minute Quadrangle Maps
(1:24,000 scale)

A - NE1/4 of Savageton 15' map
B - Eagle Rock
C - Neil Butte
D - Rough Creek
E - Jim Creek
F - Savageton
G - Reno Junction
H - Hilight
I - Open A Ranch
J - Buck Creek
K - South Butte
L - Little Thunder Reservoir
M - Reno Reservoir
N - Piney Canyon NW
O - Piney Canyon NE.



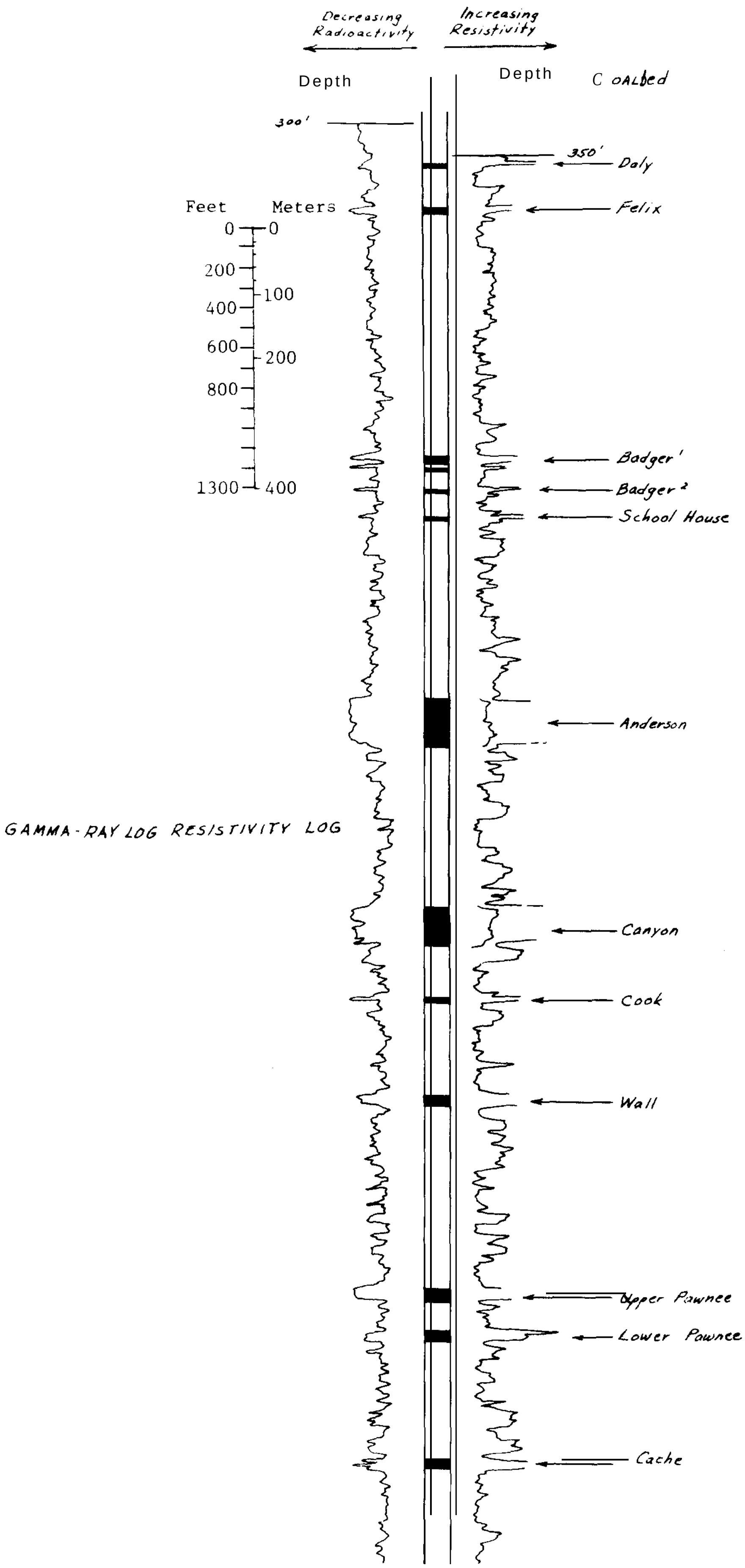



**Figure 4-11** Typical Log Response of Some Coalbeds in the Eastern Portion of Powder River Basin (From Denson, Dover, and Osmonson, 1978).

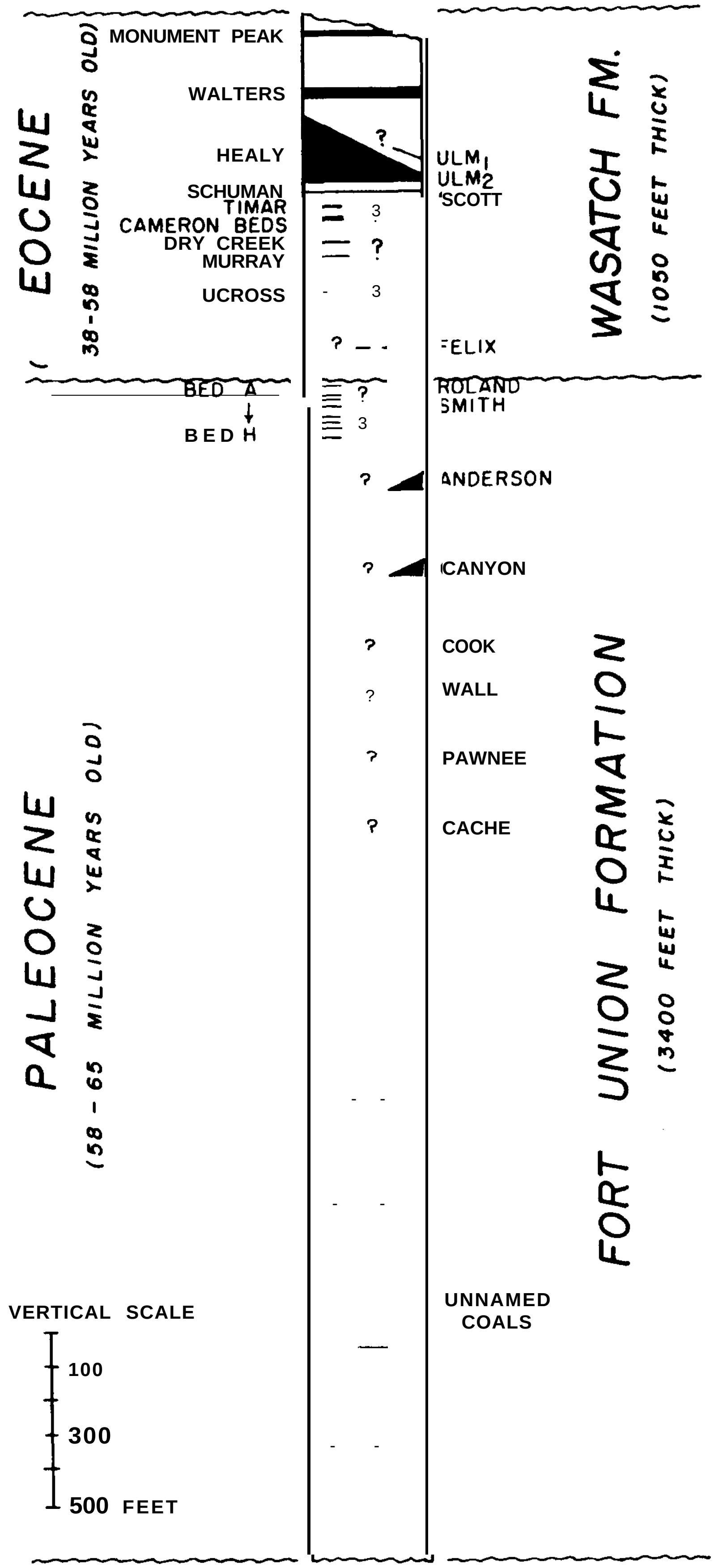



**Figure 4-12** Stratigraphic Column Showing Coalbeds in Johnson County, Wyoming (Wendell, et al, 1976)

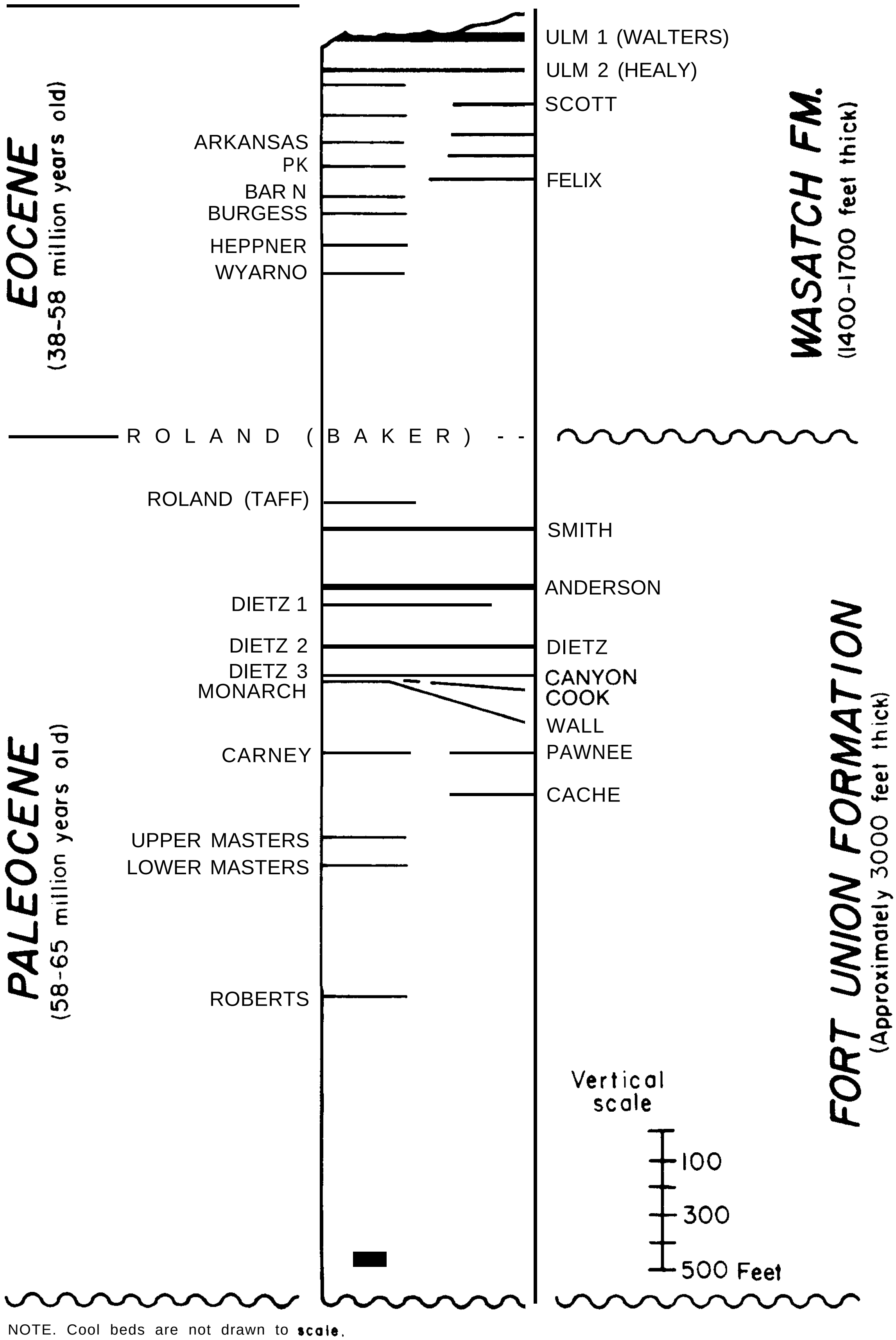



**Figure 4-13** Stratigraphic Column Showing Coalbeds in Sheridan County, Wyoming (Lageson, et al, 1978)

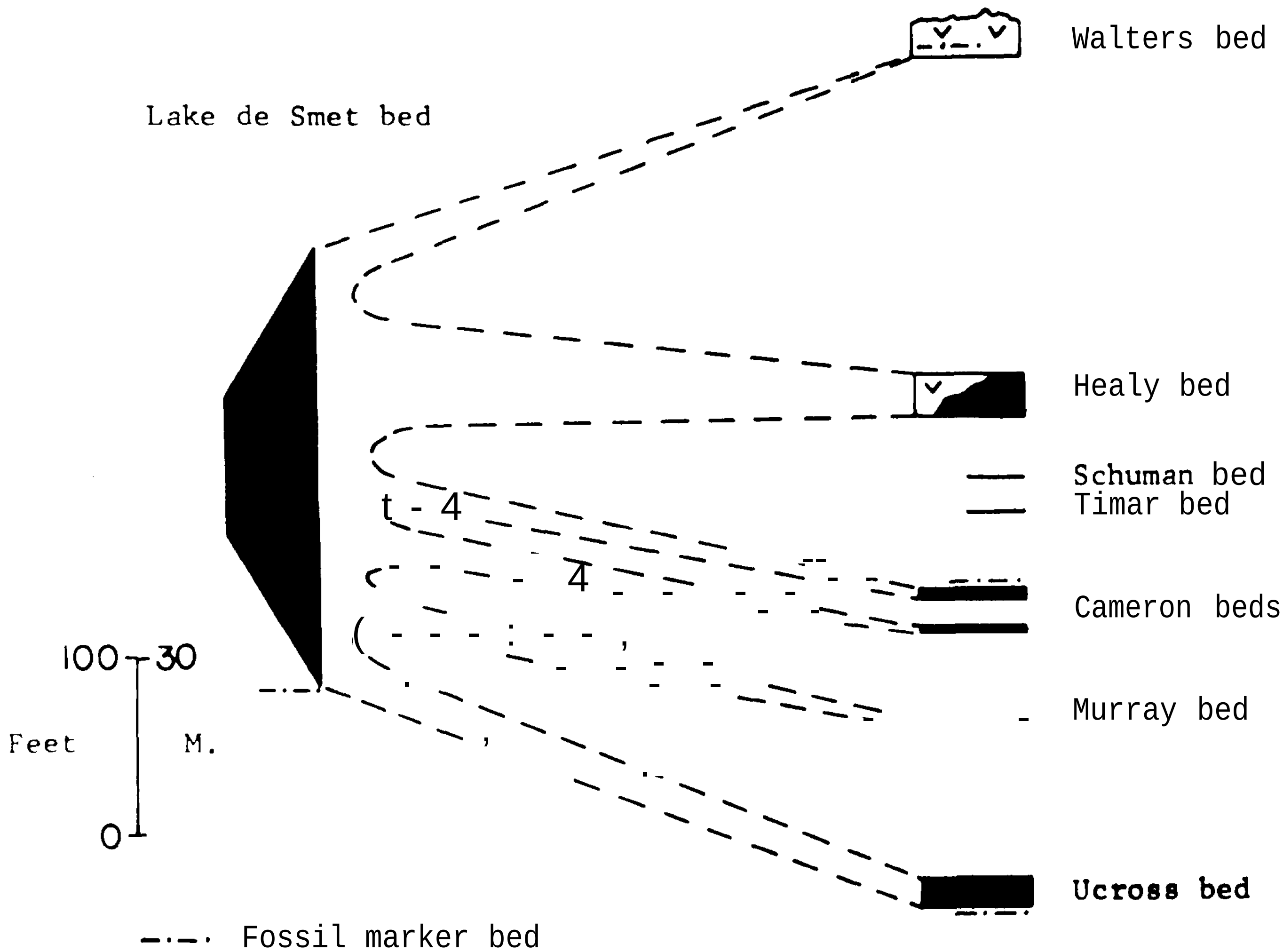



**Figure 4-14** Diagram of the Lake de Smet Coalbed Showing its Relationship to the Major Coalbeds to the East (Obernyer, 1978).

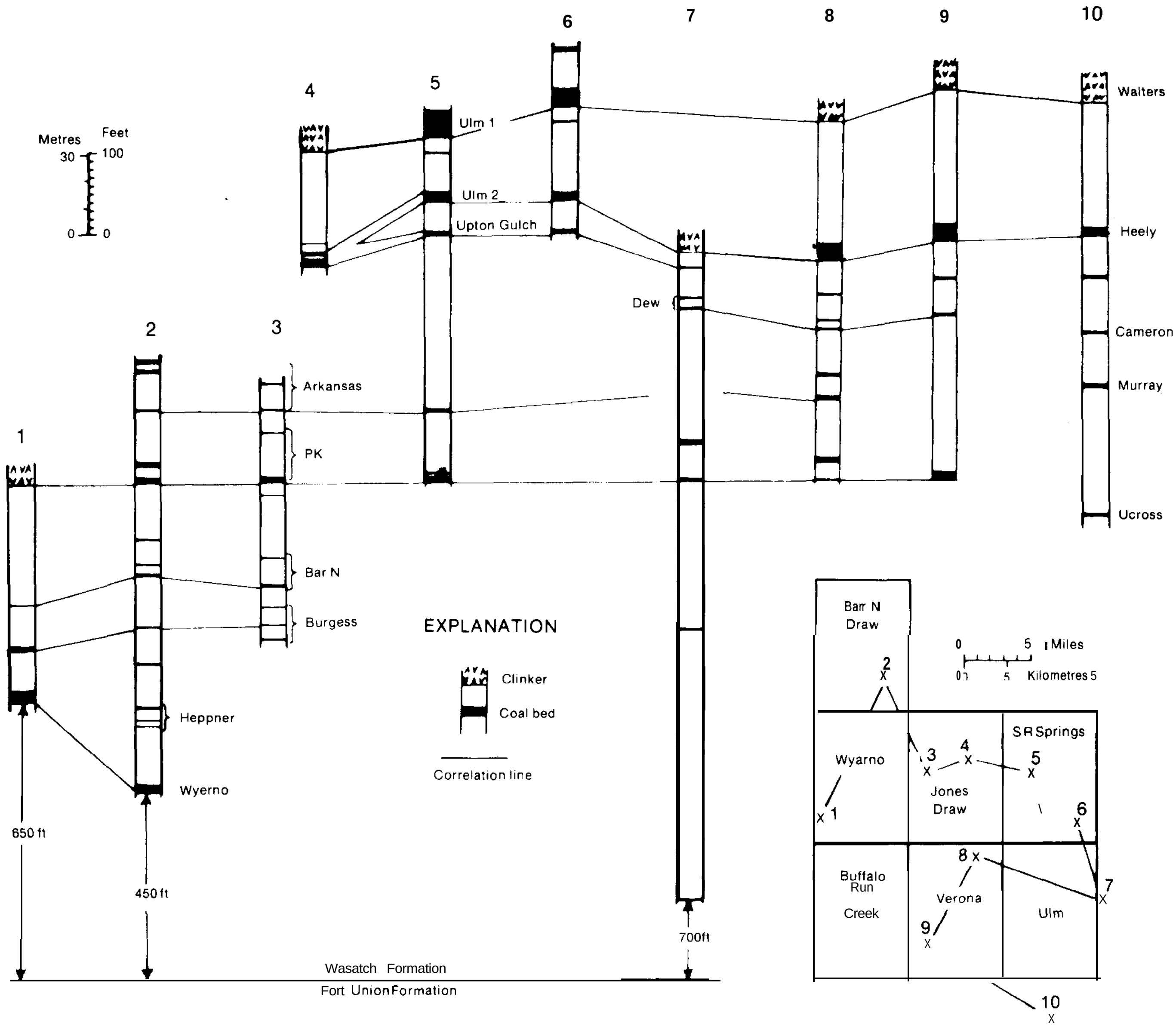



**Figure 4-15** Stratigraphic Sections Showing Coalbeds and Zones of the Upper Part of the Wasatch Formation East of Sheridan, Wyoming, and their Relation to Coalbeds in the Buffalo-Lake De Smet Area (Section 10). All Sections are from Outcrop Measurements, Except No. 7, Which is from the Gamma Ray Log of the Anshutz-Moncrief-Sohio 1 Faddis Kennedy Well (Culbertson and Maple, 1976).

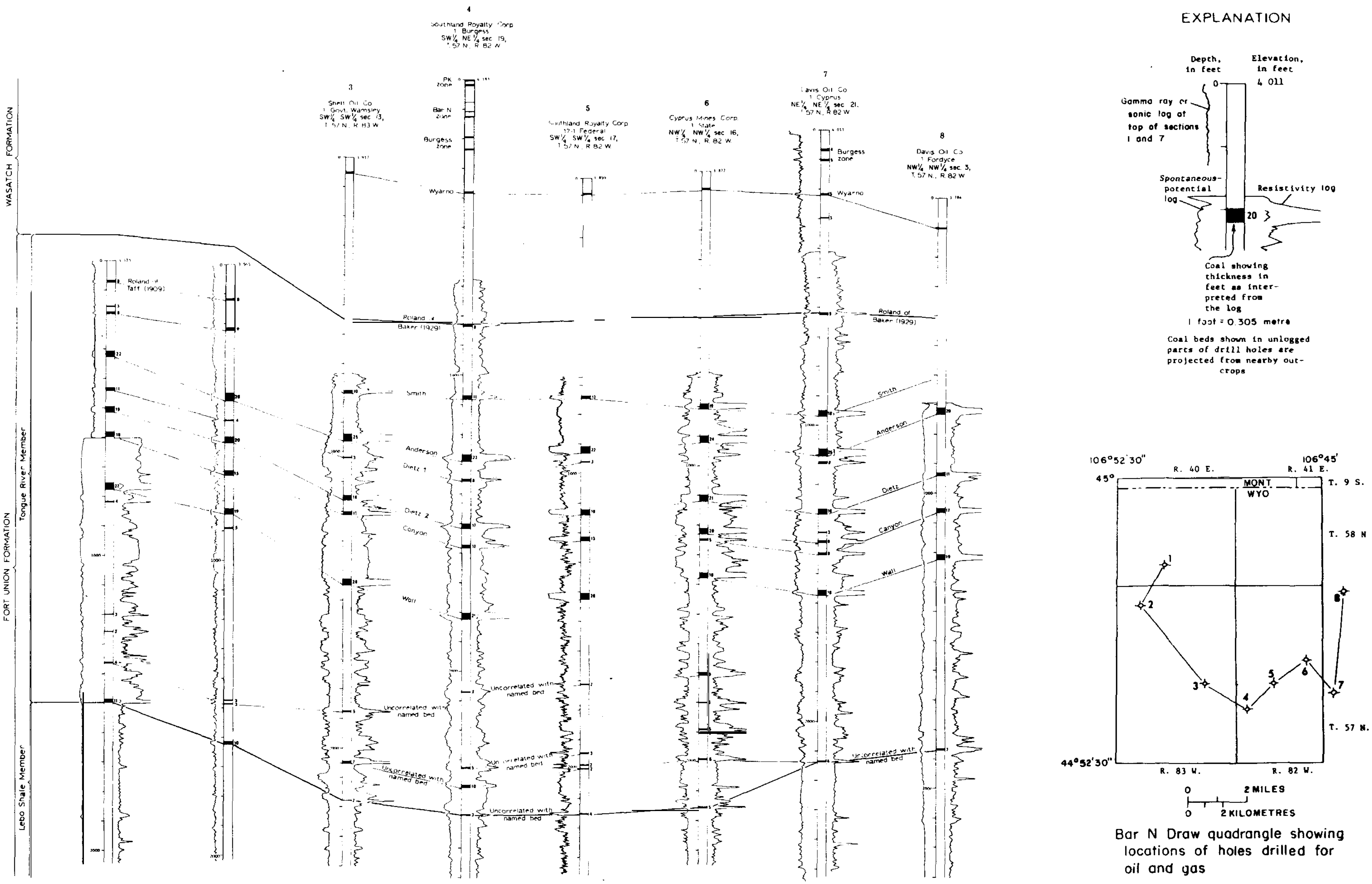



**Figure 4-16** Electric Log Correlations Showing Coalbeds in the Bar N Draw Quadrangle, Sheridan Coal Field (From Mapel, 1976).

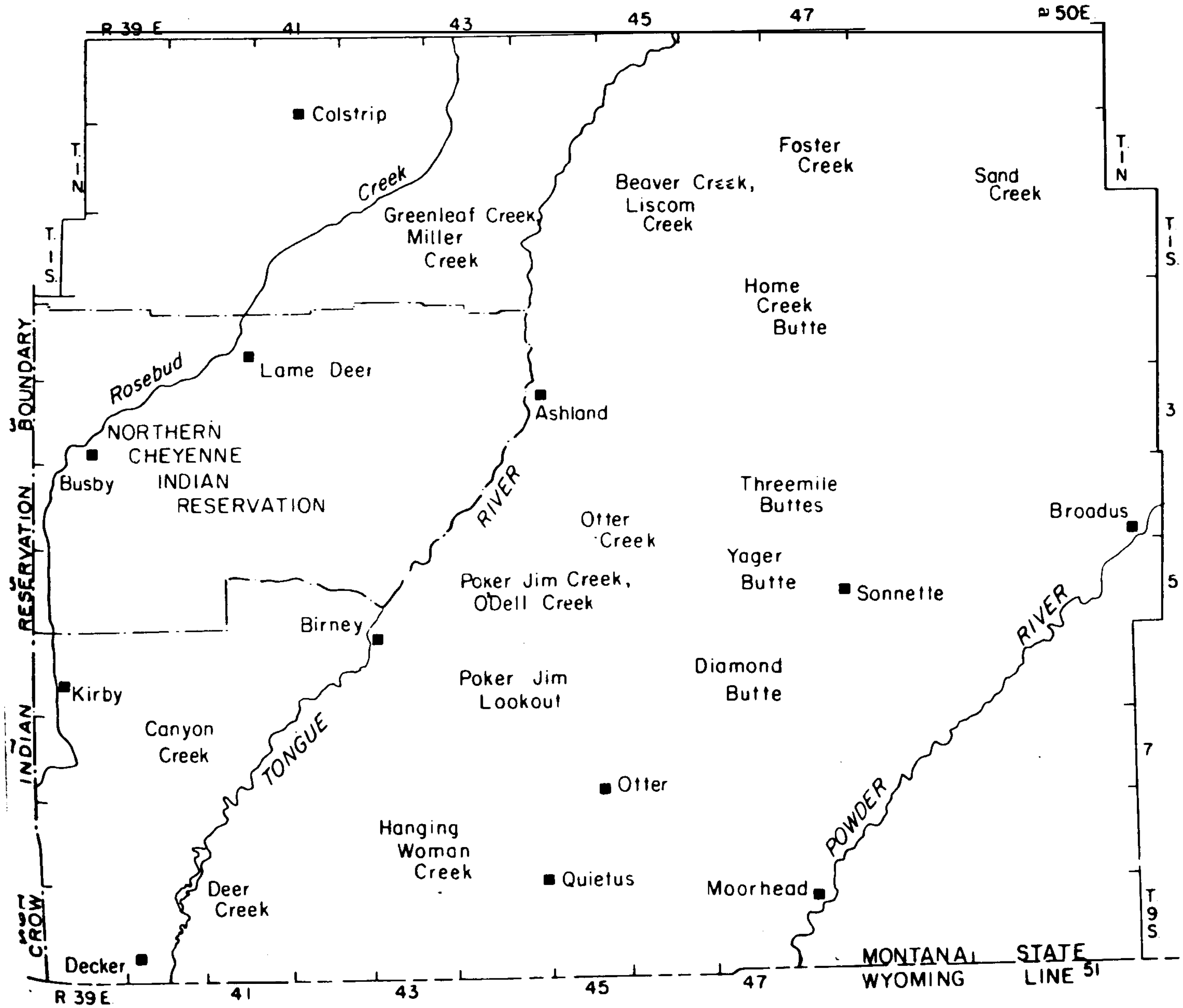



**Figure 4-17** Location Map Showing Some of the Coal Deposits of the Northern Powder River Basin, Montana (Matson and Pinchock, 1976).

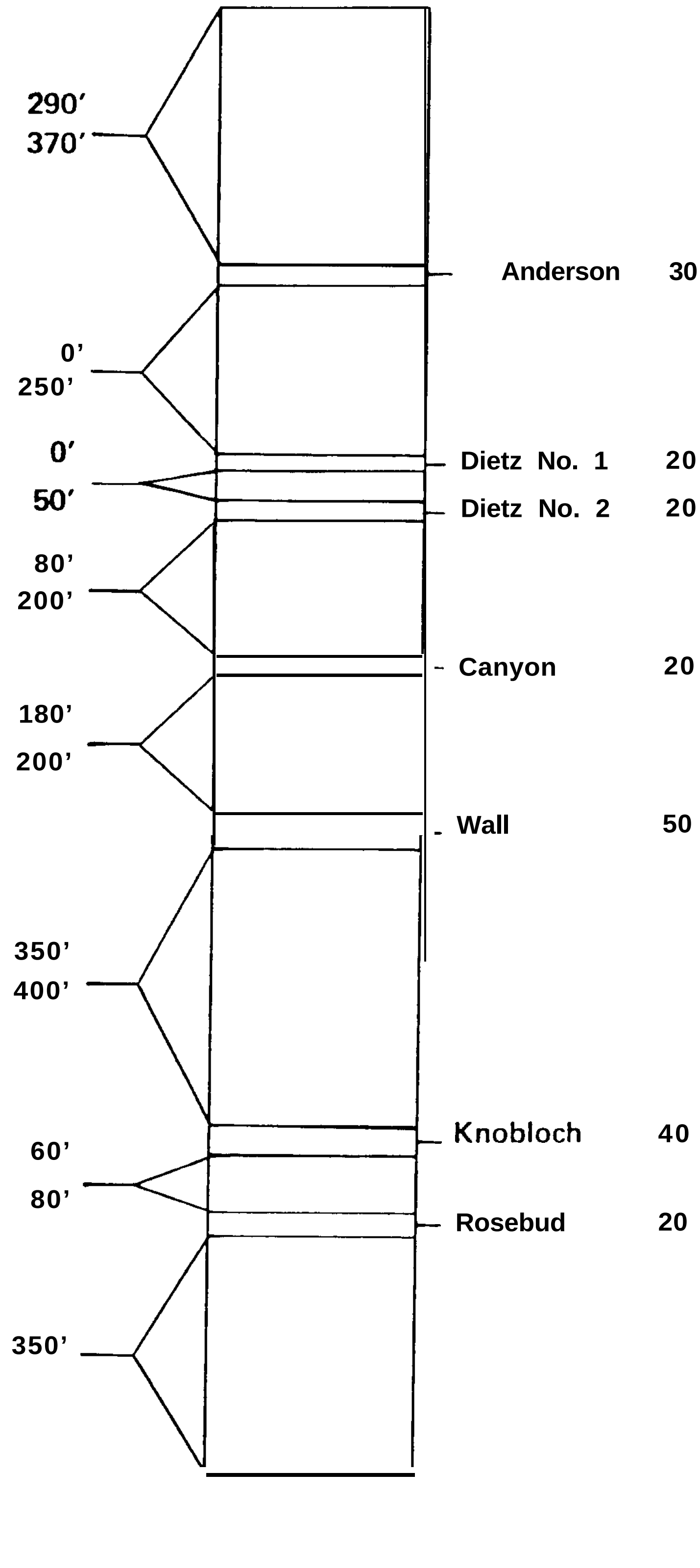



**Figure 4-18** Stratigraphic Diagram Showing Distribution and Thickness of the Important Coalbeds in the Tongue River Member, Northern Powder River Basin, Montana (Matson and Pinchock, 1976).

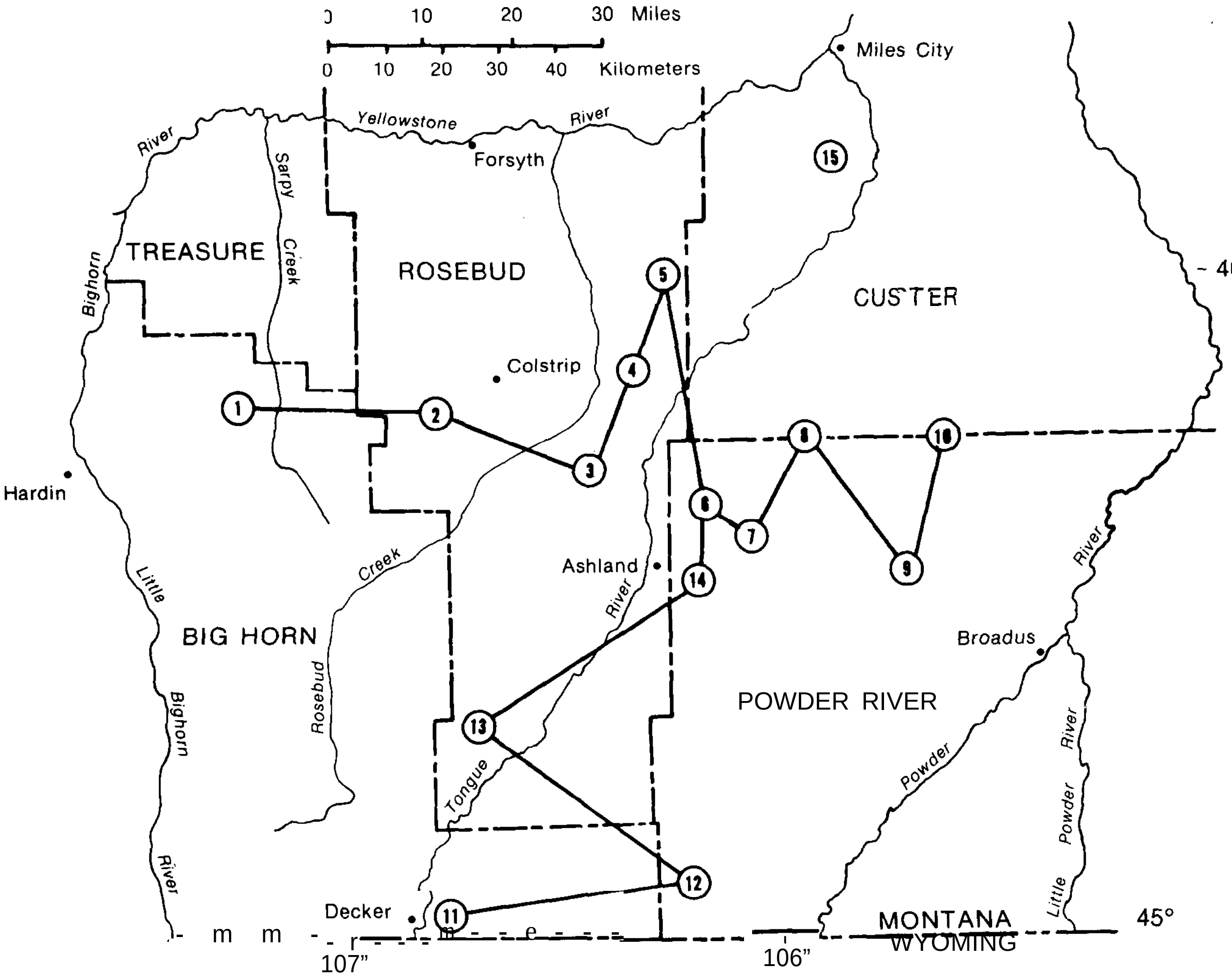



**Figure** 4-19 Location of Stratigraphic Sections Shown in Figures 4-20 and 4-21 (Maple and Swanson, 1977, **p20**)

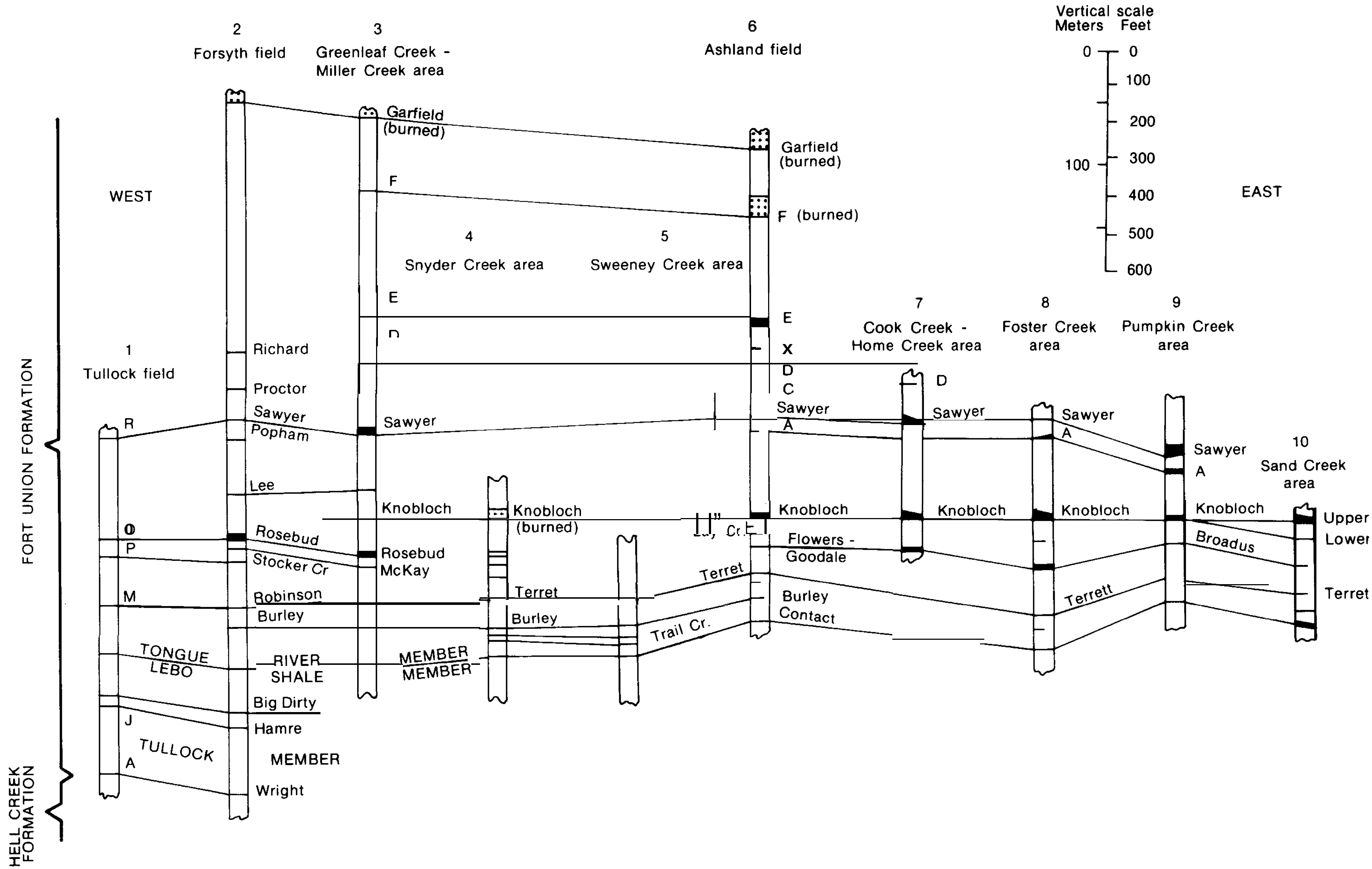



**Figure 4-20** East-West Correlation of Coalbeds, Northern Powder River Basin, Locations of Sections Shown on Figure 4-19 (From Mapel and Swanson, 1977, **p**. 19).

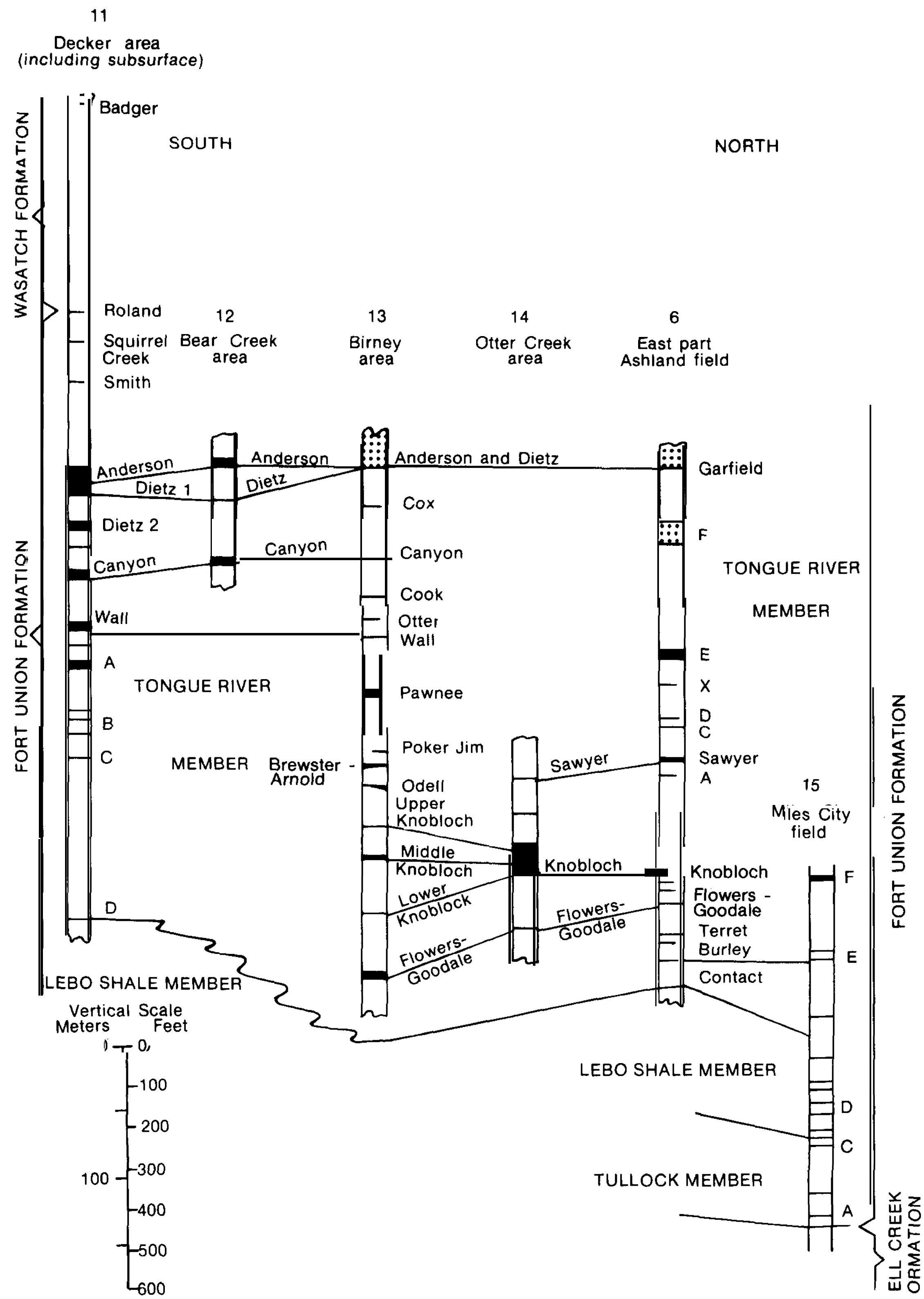



**Figure 4-21** North-South Correlation of Coalbeds Northern Powder River Basin, Montana. Location of Sections Shown on Figure 4-19 (Mapel and Swanson, 1977, p.18).

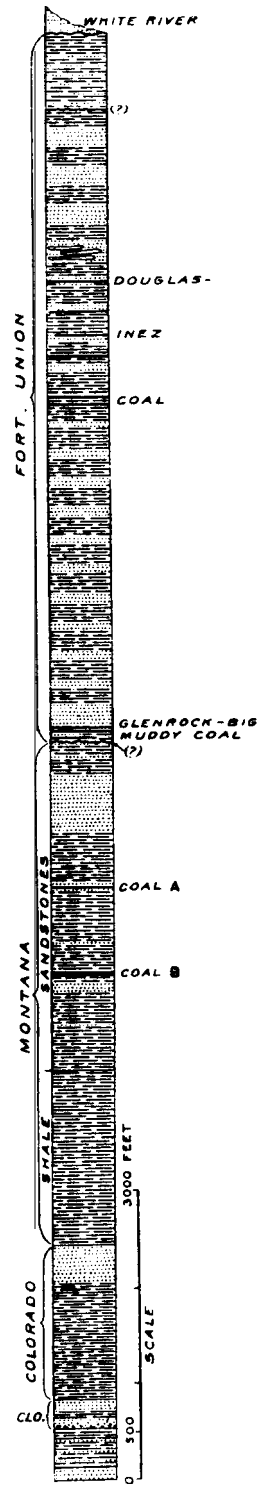



**Figure** 4-22 Stratigraphic Column of the Glenrock Coal Field (Shaw, 1909, p. 155). Though Nomenclature in Above Stratigraphic Section is not Current, Relative Stratigraphic Position and Lithology are Representative.

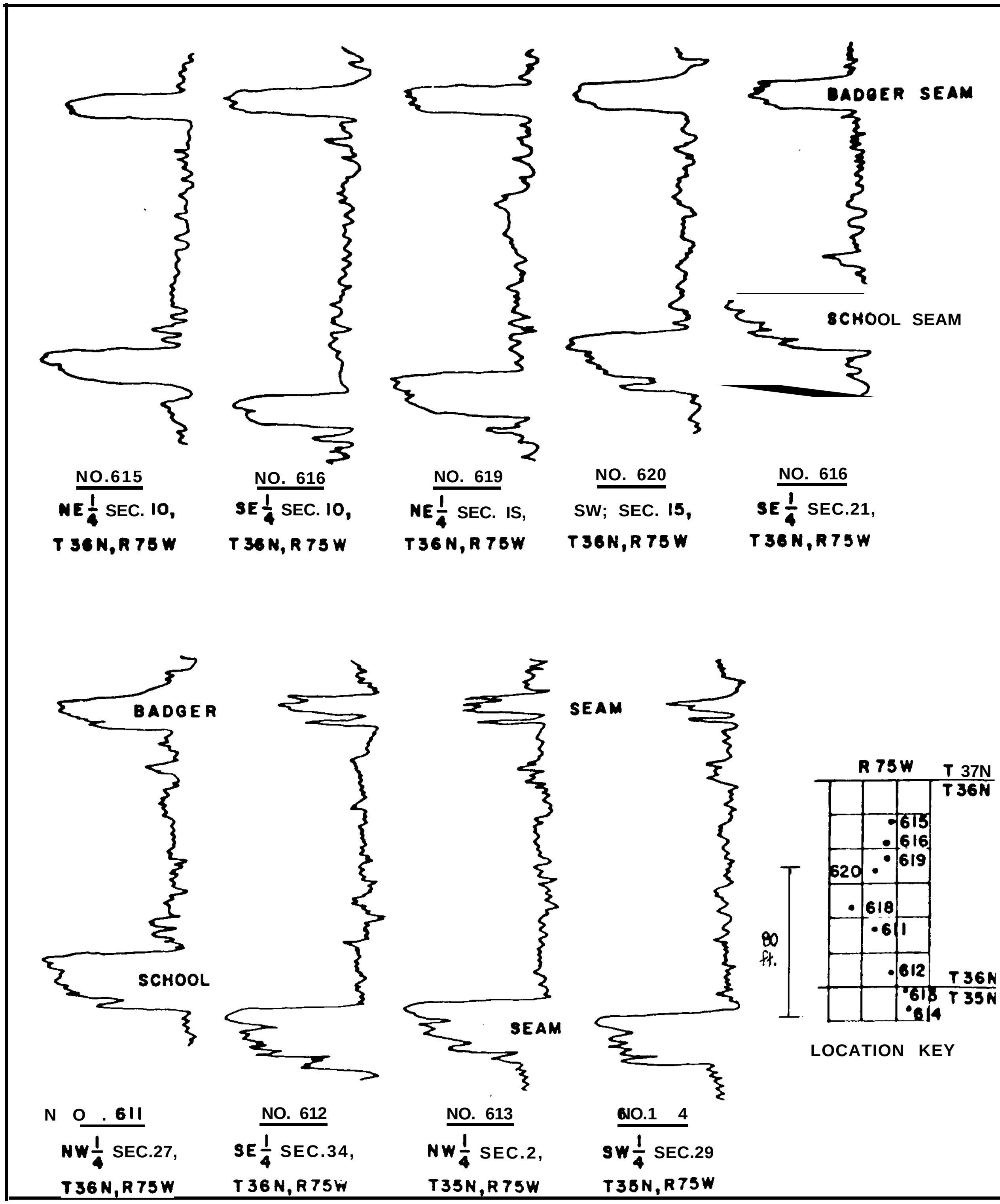



**Figure** 4-23 Gamma-Ray Logs from Drill Holes in the Dave Johnston Coal Deposit (From Duell, 1969).

**Table** 4-4 Summary of Fracture and Cleat Orientations as Determined in Four Studies of Coal-Bearing Rocks of the Powder River Basin (Henkle, Muhm, **DeBuyl**, 1978).

| Author | Study area | Major sets |
|---|---|---|
| Stone and Snoeberger (1976). | Southwest of Gillette (Felix coal). | N. **24°** W.<br>N. 78” E. |
| Glass (1975) | Gillette area (Anderson Canyon coal). | N. 10” W.-N. **5°** E.<br>N. 85” E.-S. **88°** E.<br>N. **56°-70°** E.<br>N. **26°-38°** E.<br>N. **30°** W.<br>N. **70°-82°** W.<br>N. **50°-60°** W. |
| Lee, Smith and Savage (1976). | Sheridan-Decker Coal Field. | N. 45” W<br>N. 37” E.<br>N. 13” E. |
| Henkle, Muhm **& DeBuyl** (1977). | 15 mi northwest of Gillette. | N. **35°-45°** W.<br>N. **45°-55° E**.<br>N. 5” W.-N. 5” E.<br>N. 75” E.-S. 85” E. |

**Table 4-5** Existing and Proposed Coal Mines and Projected Production (Millions of Tons) in the Powder River Basin, Wyoming and Montana. Location of Mines Shown in Figure 4-8 (Mapel and Swanson, 1977; Wyoming Department of Economic Planning and Development, 1978).

| Area | EASTERN | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Campbell County | | | | | | | | | | | | | | | | | | | | |
| Map Location [1] | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| Mine Status [2] | E | E | E | E | E | E | P | P | P | P | P | P | P | P | P | P | P | P | P | P | P |
| Mine Type [3] | S | S | S | S | S | S | S-U | S | S | S | S | S | S | S | S-U | S | S | S | S | S | S |
| Year \ Mine Name | Bell Ayr | Black Thunder | Cordero | Jacob's Ranch | Rawhide | Wyodak | Antelope | Buckskin | Caballo | Coal Creek | Eagle Butte | East Gillette | North Antelope | Pronghorn | Rawhide South | Rochelle | Section No. 16 | Thunderbird | Wildcat Creek | Unnamed (Falcon Coal Co.) | Unnamed (Mobil Oil) |
| 1973 | 1.0 | | | | | | | | | | | | | | | | | | | | |
| 1975 | 3.3 | | 0 | | | .786 | | | | | | | | | | | | | | | |
| 1976 | 7.2 | | 0 | | | .838 | | | | | | | | | | | | | | | |
| 1977 | 13.3 | .042 | 2.1 | | 1 | .857 | | | | | | | | | | | | | | | |
| 1978 | 17.0 | .9 | 2.5 | 2.8 | 3 | 1.75 | | | | | .45 | | | | | | 0.0 | | 0 | | |
| 1979 | 19.0 | 1.2 | 3.0 | 6.7 | 6 | 2.5 | | 0 | 1 | | 4.0 | | | | | | 1.0 | | 0 | | |
| 1980 | 15.0 | 3.9 | 3.5 | 9.6 | 6 | 2.5 | | 0 | 3 | | 8.0 | 4 | | | | | 2.0 | | 0 | | |
| 1981 | 15.0 | 6.6 | 4.5 | 10.0 | 7 | 2.5 | | 2.5 | 5 | 1.7 | 8.7 | 6 | | | | | 4.0 | | 0 | | |
| 1982 | 15.0 | 10.0 | 5.5 | 11.0 | 10 | 2.5 | | 4.0 | 5 | 4.0 | 13.6 | 11 | | 2.0 | | | 4.0 | | 0 | | |
| 1983 | 15.0 | 15.0 | 7.5 | 12.5 | 10 | 2.5 | | 4.0 | 5 | 6.5 | 16.6 | 11 | | 3.5 | | | 4.0 | | 0 | | |
| 1984 | 15.0 | 20.0 | 10.0 | 14.5 | 10 | 5.0 | | 4.0 | 5 | 8.5 | 17.4 | 11 | | 5.0 | | | 4.0 | | | | |
| 1985 | 15.0 | 20.0 | 12.0 | 14.5 | 10 | 5.0 | | 4.0 | 5 | 10.0 | 19.0 | 11 | | 5.0 | | | 4.0 | | | | |
| 1990 | 15.0 | | | | 10 | 5.0 | | 4.0 | 5 | 10.0 | 20.0 | | | 5.0 | | | | | | | |

| Area | WESTERN | | | | | | | SOUTHERN | | NORTHERN | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sheridan County | | | | | | Johnson Co. | Converse | | Rosebud | | Big Horn | |
| Map Location [1] | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| Mine Status [2] | E | E | E | P | P | P | P | E | P | E | E | E | E |
| Mine Type [3] | S | S | S | S | S | S | S | S | S | S | S | S | S |
| Year \ Mine Name | Ash Creek Mining | Big Horn | Black Mountain | Welch | Dutchman | Spring Creek | (Lake De Smet Area) (Texaco Oil) | Dave Johnson | Stevens North | Big Sky | Colstrip | Deaker No. 1 | Sarpy Creek |
| 1973 | | | | | | | | | | | | | |
| 1975 | | .787 | | .018 | | | | 3.2 | | 2.080 | 6.407 | 9.175 | 4.048 |
| 1976 | | .730 | | | | | | 2.7 | | | | | |
| 1977 | | 2.4 | | | | | | 3.2 | | | | | |
| 1978 | | 3.0 | | | | | | 3.1 | | | | | |
| 1979 | .2 | 3.0 | | | | | | 3.1 | | | | | |
| 1980 | .45 | 3.0 | | | | | | 3.1 | | | | | |
| 1981 | .5 | 3.0 | | | | | | 3.1 | | | | | |
| 1982 | .5 | 3.0 | | | | | | 3.1 | | | | | |
| 1983 | .5 | 3.0 | | | | 10 | | 3.1 | | | | | |
| 1984 | .5 | 3.0 | | | | 10 | | 3.1 | | | | | |
| 1985 | .5 | 3.0 | | | | 10 | | 3.1 | | | | | |
| 1990 | .5 | 3.0 | | | | 10 | | 3.1 | | | | | |

1 Map Location: See Figure 4-8
2 Mine Status: E = Existing; P = Proposed or Under Construction
3 Mine Type: S = Strip; U = Underground

**Table** 4-6 Averaged Analyses of **Coalbeds** in the Fort Union and Wasatch Formations of Campbell County (Breckenridge, et al, (1974).

| | | WASATCH FORMATION | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ULM 2 (3)[1] | | SCOTT (3) | | FELIX (42) | | UNSPECIFIED (6) | |
| | As-received | Range | Average | Range | Average | Range | Average | Range | Average |
| PROXIMATE | MOISTURE (%) | 28.1-29.7 | 28.9 | 25.0-32.2 | 29.1 | 17.8-33.5 | 28.0 | 23.7-29.6 | 27.6 |
| PROXIMATE | VOLATILE MATTER (%) | 31.6-33.2 | 32.2 | 29.7-30.9 | 30.2 | 29.1-36.4 | 31.7 | 26.9-30.9 | 29.2 |
| PROXIMATE | FIXED CARBON (%) | 30.8-33.2 | 32.4 | 27.5-29.8 | 28.8 | 28.4-39.4 | 32.5 | 25.4-33.3 | 29.9 |
| PROXIMATE | ASH (%) | 5.6-7.6 | 6.5 | 8.2-15.8 | 11.9 | 4.5-14.9 | 7.8 | 6.2-23.2 | 13.3 |
| | SULFUR (%) | 0.60-1.24 | 0.94 | 0.87-2.22 | 1.75 | 0.32-3.26 | 0.89 | 1.07-4.16 | 2.19 |
| | HEAT VALUE (BTU/POUND) | 7901-8029 | 7965 | 7241-7425 | 7330 | 7180-9535 | 8053 | 6501-8215 | 7418 |
| | | FORT UNION FORMATION | | | | | | | |
| | | SMITH (1) | | ANDERSON (23) | | CANYON 9) | | WYODAK (53) | |
| PROXIMATE | MOISTURE (%) | | 31.8 | 24.9-34.1 | 29.5 | 26.5-31.5 | 29.6 | 23.4-36.9 | 29.8 |
| PROXIMATE | VOLATILE MATTER (%) | - | 28.7 | 26.5-34.5 | 30.1 | 28.7-33.3 | 30.7 | 26.5-32.7 | 30.7 |
| PROXIMATE | FIXED CARBON (%) | - | 34.8 | 29.0-38.0 | 33.9 | 31.8-38.4 | 34.6 | 29.6-41.4 | 33.5 |
| PROXIMATE | ASH (%) | - | 4.7 | 3.5-12.2 | 6.5 | 3.1-7.4 | 5.1 | 2.9-12.2 | 6.0 |
| | SULFUR (%) | - | 0.63 | 0.17-1.13 | 0.52 | 0.14-0.92 | 0.34 | 0.20-1.20 | 0.50 |
| | HEAT VALUE (BTU/POUND) | | 7991 | 7128-8737 | 7979 | 7537-8609 | 8286 | 7420-9306 | 8224 |

[1]Number of samples averaged. (Table compiled from analyses published by the U. S. Geological Survey and the U. S. Bureau of Mines.)

**Table** 4-7 Range and Average Thickness of Some Fort Union **Coalbeds** from Seven Recent U.S.G.S. Quadrangle Maps in the Eastern Powder River Basin

| | CROFTON MF - 826 | TRUMAN DRAW MF - 917 | WILDCAT MF - 735 | (CROFTON 1 SW) HOMESTEAD DRAW MF - 544 | RECLUSE MF - 732 | (TOWNSEND SPRING) ORIVA NW MF 545 | GILLETTE WEST MF - 974 |
|---|---|---|---|---|---|---|---|
| ANDERSON | $\overline{33}$<br>26 36<br>Thin Parting | $\overline{29}$<br>24 39<br>2 beds | $\overline{33}$<br>25 -44<br>1 5 beds<br>"Swartz-Anderson" | $\overline{24}$<br>18 - 40 | $\overline{20}$<br>8 34<br>"Swartz-Anderson"<br>l-3 beds | $\overline{33}$<br>5 42 | Wyodak bed<br>$\overline{87}$<br>6 7 108<br>1 - 4 beds |
| DIETZ | $\overline{9}$<br>**7 10** | $\overline{10}$<br>6 17<br>1 2 beds | $\overline{22}$<br>12-46<br>combined w/Canyon<br>at 3 wells 65-70' thick | $\overline{28}$<br>10 - 40 | $\overline{24}$<br>12-37<br>1 4 beds thin parting | $\overline{30}$<br>3 32 | |
| CANYON | 49<br>32 60<br>Parting | $\overline{29}$<br>4 53<br>2 - 4 beds | $\overline{27}$<br>17-35<br>combined at 3 wells 65-70' thick | $\overline{10}$<br>10 - 33 | $\overline{24}$<br>10 - 30<br>1 4 beds<br>thin partings | $\overline{45}$<br>11 -96 | |
| COOK | 25 $\overline{34}$ 45 | $\overline{20}$<br>12 -26<br>1 2 beds | $\overline{8}$<br>3 - 13<br>1 bed | $\overline{14}$<br>5 - 30<br>2 beds | $\overline{6}$<br>4 12 feet<br>1 2 beds | $\overline{7}$<br>3 21<br>2 beds | |
| WALL | | $\overline{38}$<br>10-66<br>1 4 beds | $\overline{26}$<br>14-45 | $\overline{20}$<br>10 - 33 | 25<br>13-37<br>1 3 beds | | $\overline{9}$<br>3 - 12<br>1 bed |
| UPPER PAWNEE | $\overline{32}$<br>19 - 38<br>1 - 2 beds | $\overline{14}$<br>4 - 25<br>1 2 beds | $\overline{8}$<br>5 - 10 | i i<br>4 - 19 | 23<br>11 - 36<br>1 - 2 beds | | $\overline{10}$<br>2 - 17 |
| LOWER PAWNEE | | | $\overline{11}$<br>7 - 14 | $\overline{7}$<br>3 - 11 | | | $\overline{8}$<br>3 - 17 |
| CACHE | 4 $\overline{13}$ 20 | $\overline{12}$<br>4 - 26<br>1 bed | 8 $\overline{11}$ 19 | 3 $\overline{11}$ 17 | $\overline{8}$<br>4 - 16<br>1 2 beds | | $\overline{24}$<br>20 - 33<br>1 - 3 beds |
| NOTES | At least 3 unnamed beds in 250' section below Cache, each being 2 - 13' thick. | 206' of coal in 1500' section in hole T-8 (18 beds). At least 4 - 6 unnamed beds in 400' section below Cache, each being 3 - 12' thick. | At least 3 beds below Cache 3 - 12 feet thick in 200' section. | | 1 - 6 unnamed beds in 300' section below Cache, 3 - 14' thick. | | 204 feet of coal in well 25 2000 ft. section sec 27 Anshutz - 1 Federal 048 |

Compiled from Law, 1976: McLaughlin and Hayes, 1973. Hayes, 1973: Kent. 1976 a and b. Haddock. Kent and Bohor, 1976. Kent. Haddock and Bohor, 1977

$\overline{25}$ arithmatic average of recorded thickness over 3 feet, excluding partings
5 - 30 range of recorded thickness over 3 feet

**Table 4-8** Coal Analyses from Johnson County, Wyoming (Wendell, et al, 1976).

| | As received | WASATCH FORMATION: HEALY (12)[1] Range | WASATCH FORMATION: HEALY (12)[1] Average | WASATCH FORMATION: LOWER CAMERON (5)[1] Range | WASATCH FORMATION: LOWER CAMERON (5)[1] Average | FORT UNION FORMATION: BED E[3] (2)[1] Range | FORT UNION FORMATION: BED E[3] (2)[1] Average | FORT UNION FORMATION: BED B[4] Single Analysis | FORT UNION FORMATION: LOWERMOST BED[5] Single Analysis |
|---|---|---|---|---|---|---|---|---|---|
| PROXIMATE | MOISTURE (%) | 23.6-31.2 | 29.1 | 26.8-31.1 | 28.8 | 18.8-23.5 | 21.1 | 28.8 | 23.6 |
| PROXIMATE | VOLATILE MATTER (%) | 28.6-33.1 | 30.5 | 28.7-32.8 | 29.8 | 35.7-35.6 | 35.6 | | |
| PROXIMATE | FIXED CARBON (%) | 35.4-32.8 | 34.2 | 34.7-27.9 | 31.7 | 37.9-35.7 | 36.8 | | |
| PROXIMATE | ASH (%) | 2.2-9.7 | 6.3 | 7.2-12.5 | 9.6 | 5.2-14.6 | 6.5 | | |
| ULTIMATE[2] | HYDROGEN (%) | 6.1-6.7 | 6.5 | 6.0-6.6 | 6.4 | 6.5 | 6.5 | 6.7 | 7.8 |
| ULTIMATE[2] | CARBON (%) | 45.4-48.3 | 46.6 | 42.7-44.6 | 43.6 | 51.2 | 51.2 | | |
| ULTIMATE[2] | NITROGEN (%) | 0.7-1.0 | 0.8 | 0.5-0.8 | 0.6 | .7 | .7 | | |
| ULTIMATE[2] | OXYGEN (%) | 34.2-40.6 | 38.8 | 37.5-40.7 | 39.1 | 35.9 | 35.9 | | |
| ULTIMATE[2] | SULFUR (%) | 0.3-1.0 | 0.6 | 0.4-1.4 | 0.9 | 0.5-0.6 | 0.5 | 0.6 | 0.7 |
| | HEAT VALUE (BTU/POUND) | 7515-8270 | 7910 | 7344-7627 | 7492 | 7980-9157 | 8729 | 7931 | 8446 |

[1] Number of samples averaged for proximate analysis.
[2] Ultimate analysis does not add up to 100% because fewer analyses were averaged.
[3] Bed E of Wegemann (1912) in Coal Basin No. 2 of the Sussex Field.
[4] Bed B of Wegemann (1912) or Bed E of Hose (1955) in Coal Basin No. 2 of the Sussex Field.
[5] Lowermost bed of Wegemann (1912) in Coal Basin No. 4 of the Sussex Field.

(Table compiled from channel, tipple or core samples analyzed by the U. S. Bureau of Mines. Only a few of the analyses represent the full thickness of a given bed. Also with the exception of one tipple sample, noncoaly partings and dirty (bony) coal were removed from each sample before analysis. Considerable core loss was noted in 8 core samples of the Healy coal).

**Table 4-9** Coal Analyses of Fort Union Coals from Sheridan County, Wyoming (Lageson, et al, 1978)

| | | FORT UNION FORMATION | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CARNEY | | | DIETZ NO. 1 | DIETZ NO. 2 | | | DIETZ NO. 3 | | | MASTERS'[1] | | | MONARCH | | | ROLAND[2] | SMITH |
| | AS RECEIVED | RANGE | AVER. | AVER. | | RANGE | AVER. | AVER. | RANGE | AVER. | AVER. | RANGE | AVER. | AVER. | RANGE | AVER. | AVER. | | |
| | NUMBER OF ANALYSES | 46[3] (13)[4] | 46 | 13 | 1 | 14[3] (4)[4] | 14 | 4 | 11[3] (2)[4] | 11 | 2 | 6[3] (2)[4] | 6 | 2 | 76[3] (18)[4] | 76 | 18 | 1 | 1 |
| PROXIMATE | MOISTURE (%) | 21.2-25.8 | 24.1 | 23.6 | 24.7 | 21.3-23.6 | 22.4 | 22.4 | 19.1-25.7 | 23.8 | 21.8 | 22.7-25.8 | 24.0 | 23.3 | 19.8-25.0 | 23.0 | 22.8 | 23.5 | 23.9 |
| | VOLATILE MATTER (%) | 29.5-35.8 | 32.0 | 32.3 | 37.6 | 31.3-34.1 | 33.2 | 32.8 | 30.0-34.8 | 31.6 | 33.0 | 32.4-34.8 | 33.9 | 34.5 | 31.2-38.3 | 33.9 | 33.4 | 34.5 | 35.8 |
| | FIXED CARBON (%) | 34.9-43.7 | 40.3 | 40.3 | 33.0 | 35.5-40.2 | 37.8 | 38.1 | 33.9-41.7 | 39.5 | 40.7 | 36.6-38.2 | 37.5 | 37.4 | 33.1-42.1 | 38.8 | 39.2 | 37.2 | 34.3 |
| | ASH (%) | 2.6-8.6 | 3.7 | 3.8 | 4.7 | 5.0-8.5 | 6.7 | 6.8 | 3.5-8.6 | 5.2 | 4.6 | 3.8-5.9 | 4.7 | 4.9 | 2.8-11.2 | 4.4 | 4.6 | 4.8 | 6.1 |
| ULTIMATE | HYDROGEN (%) | 5.8-6.5 | | 6.3 | 6.2 | 6.1-6.4 | | 6.3 | 6.1-6.3 | | 6.2 | 6.1-6.3 | | 6.2 | 5.8-6.9 | | 6.4 | | 6.5 |
| | CARBON (%) | 52.3-55.3 | | 53.8 | 51.5 | 50.6-53.6 | | 52.2 | 52.6-56.6 | | 54.5 | 52.7-53.7 | | 53.1 | 49.2-55.3 | | 53.9 | | 51.0 |
| | NITROGEN (%) | 0.9-1.2 | | 1.1 | 1.1 | 1.2-1.3 | | 1.2 | 1.1-1.4 | | 1.3 | 1.0-1.2 | | 1.1 | 1.0-1.3 | | 1.1 | | 1.1 |
| | OXYGEN (%) | 32.5-36.1 | | 34.7 | 36.1 | 31.7-33.1 | | 32.5 | 31.3-34.7 | | 33.0 | 34.1-34.8 | | 34.5 | 30.4-35.0 | | 33.3 | | 34.6 |
| | SULFUR (%) | 0.3-0.8 | 0.4 | 0.4 | 0.4 | 0.7-1.3 | 1.0 | 1.1 | 0.3-0.6 | 0.5 | 0.5 | 0.3-0.7 | 0.5 | 0.3 | 0.2-1.2 | 0.5 | 0.6 | 1.4 | 0.8 |
| | HEAT VALUE BTU/POUND | 8910-9720 | 9240 | 9260 | 8903 | 9000-9430 | 9200 | 9200 | 8730-9710 | 9060 | 9360 | 9010-9360 | 9230 | 9250 | 8450-9820 | 9350 | 9410 | 9010 | 8820 |

[1] Undifferentiated Upper and Lower Masters [2] Roland of Taft [3] Number of analyses used to determine range for proximate analysis, sulfur, and heat value
[4] Number of analyses used to determine range for hydrogen, carbon, nitrogen, and oxygen

(Table compiled from channel, tipple, or delivered samples analyzed by the U.S. Bureau of Mines. Only a few analyses represent the full thickness of a given bed. Noncoaly partings and dirty (bony) coal were removed from channel samples)

**Table 4-10** Analyses of Coal Samples from Three Beds in the Wasatch Formation, Sheridan Coal Field. All Samples are from Outcrops Except **D50515**, Which was a Fresh Sample from a Mine in the Healy Bed in the Buffalo-Lake De Smet Area (From Culbertson and Maple, 1976).

| Sample No. | Location Sec. | T. | R. | Form of analysis | Moisture | Volatile matter | Fixed carbon | Ash | Heating value (Btu) | Sulfur | Forms of sulfur Sulfate | Pyritic | Organic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Ulm 1 bed** | | | | | | | |
| D169078 | 26 | 56N. | 81W. | A | 35.9 | 30.1 | 28.4 | 5.6 | 6,290 | 1.2 | 0.06 | 0.34 | 0.85 |
| | | | | B | — | 46.9 | 44.4 | 8.7 | 9,820 | 2.0 | .09 | .53 | 1.32 |
| | | | | C | — | 51.4 | 48.6 | — | 10,760 | 2.1 | .10 | .59 | 1.45 |
| D 169770 | 17 | 54N. | 80W. | A | 34.6 | 32.1 | 27.9 | 5.4 | 6,190 | 0.5 | 0.19 | 0.03 | 0.30 |
| | | | | B | — | 49.1 | 42.7 | 8.2 | 9,470 | .8 | .29 | .05 | .46 |
| | | | | C | — | 53.5 | 46.5 | — | 10,320 | .9 | .32 | .05 | .509 |
| D169771 | 17 | 54N. | 80W. | A | 37.1 | 32.2 | 23.3 | 7.4 | 5,290 | 0.8 | 0.28 | 0.06 | 0.42 |
| | | | | B | — | 51.2 | 37.0 | 11.8 | 8,400 | 1.2 | .44 | .10 | .67 |
| | | | | C | — | 58.0 | 42.0 | — | 9,530 | 1.4 | .50 | .11 | ,-6 |
| | | | | | | **Ulm 2 bed** | | | | | | | |
| D 169079 | 26 | 56N. | 81W. | A | 32.1 | 33.2 | 31.8 | 2.9 | 7,880 | 1.9 | 0.21 | 0.49 | 1.1; |
| | | | | B | — | | 46.8 | 4.3 | 11,590 | 2.8 | .31 | .71 | 1.73 |
| | | | | C | — | 51.1 | 48.9 | — | 12,120 | 2.9 | .33 | .75 | 1.81 |
| D169071 | 26 | 55N. | 82W. | A | 36.5 | 30.6 | 27.7 | 5.2 | 5,960 | 0.4 | 0.01 | 0.03 | 0.38 |
| | | | | B | — | 48.2 | 43.6 | 8.2 | 9,380 | .6 | .01 | .05 | .59 |
| | | | | C | — | 52.5 | 47.5 | — | 10,210 | .7 | .01 | .05 | .64 |
| D50515 | 1 | 53N. | 82W. | A | 30.7 | 29.8 | 34.4 | 5.1 | 7,900 | 0.4 | — | — | — |
| | | | | B | — | 43.0 | 49.7 | 7.3 | 11,400 | .5 | — | — | |
| | | | | C | — | 46.4 | 53.6 | — | 12,300 | .5 | — | — | — |
| | | | | | | **PK bed** | | | | | | | |
| D165047 | 8 | 56N. | 82W. | A | 27.4 | 31.9 | 38.4 | 2.3 | 8,320 | 3.2 | 0.37 | 0.97 | 1.90 |
| | | | | B | — | 43.9 | 52.9 | 3.2 | 11,460 | 4.5 | .51 | 1.33 | 2.62 |
| | | | | C | — | 45.4 | 54.6 | — | 11,840 | 4.6 | .53 | 1.38 | 2.71 |
| D169073 | 22 | 55N. | 82W. | A | 37.1 | 31.7 | 26.3 | 4.9 | 4,810 | 0.8 | 0.21 | 0.02 | 0.61 |
| | | | | B | — | 50.4 | 41.7 | 7.9 | 9,240 | 1.3 | .33 | .04 | .97 |
| | | | | C | — | 54.7 | 45.3 | — | 10,030 | 1.4 | .35 | .04 | 1.05 |

**Table 4-11** Typical Coal Analyses from Fort Union Coalbeds in the Northern Powder River Basin, Montana (Matson and Pinchock, 1976)

| Deposit | No of samples | Moisture | Volatile matter | Fixed carbon | Ash | Sulfur | Btu/lb |
|---|---|---|---|---|---|---|---|
| **ANDERSON COALBED** | | | | | | | |
| Decker | 8 | 23.128 | 29.856 | 39.634 | 4.310 | .291 | 9236 |
| Deer Creek | 3 | 23.197 | 28.105 | 36.640 | 11.459 | .630 | 8340 |
| Poker Jim Lookout | 8 | 29.626 | 30.013 | 35.084 | 5.277 | .375 | 7926 |
| Hanging Woman Creek | 56 | 25.990 | 29.850 | 38.642 | 5.133 | .293 | 8503 |
| Kirby | 11 | 26.716 | 28.085 | 38.471 | 4.295 | .321 | 8328 |
| West Moorhead | 3 | 26.233 | 31.133 | 37.300 | 5.333 | .367 | 8297 |
| Decker Mine (Combined Anderson-Dietz) | Tipple | 23.0 | 34.000 | 39.300 | 3.7 | .400 | 9600 |
| **DIETZ COALBED** | | | | | | | |
| Decker | 4 | 23.612 | 25.562 | 36.563 | 11.764 | .349 | 8367 |
| Deer Creek | 3 | 23.191 | 28.105 | 36.640 | 11.459 | .630 | 8340 |
| Hanging Woman Creek | 4 | 27.423 | 29.622 | 36.811 | 5.507 | .337 | 8078 |
| Kirby | 15 | 26.180 | 27.183 | 37.426 | 5.870 | .590 | 8442 |
| West Moorhead | 4 | 31.333 | 29.117 | 34.823 | 4.127 | .418 | 7990 |
| **CANYON COALBED** | | | | | | | |
| Decker | 3 | 22.863 | 29.856 | 39.737 | 1.544 | .418 | 9104 |
| Poker Jim Lookout | 3 | 30.483 | 29.466 | 35.050 | 5.002 | .371 | 8201 |
| Hanging Woman Creek | 4 | 25.155 | 29.940 | 38.542 | 6.365 | .407 | 8428 |
| Kirby | 3 | 23.780 | 29.637 | 40.770 | 5.811 | .240 | 8789 |
| West Moorhead | 12 | 28.321 | 29.779 | 36.550 | 5.343 | .420 | 8055 |
| Canyon Creek | 7 | 26.829 | 26.970 | 35.870 | 10.328 | .786 | 8192 |
| Diamond Butte | 5 | 35.128 | 27.921 | 33.033 | 3.918 | .307 | 7395 |
| Sonnette | 1 | 36.960 | 26.709 | 30.054 | 6.277 | .955 | 6904 |
| Threemile Buttes | 7 | 37.339 | 26.378 | 30.696 | 5.587 | .942 | 6861 |
| **WALL COALBED** | | | | | | | |
| Canyon Creek | 42 | 24.346 | 30571 | 40.429 | 4.629 | .305 | 9088 |
| Yager Butte | 89 | 32.663 | 28.03 | 34.391 | 4.916 | .320 | 7552 |
| **KNOBLOCH COALBED** | | | | | | | |
| Ashland | 27 | 27.664 | 20.824 | 37.633 | 4.828 | .153 | 8420 |
| Otter Creek | 28 | 28.233 | 29.915 | 36.712 | 4.710 | .367 | 8468 |
| Poker Jim Creek-O'dell Creek | 6 | 24.165 | 30.036 | 40.695 | 5.104 | .226 | 8846 |
| Greenleaf Creek-Miller Creek | 8 | 27.405 | 28.498 | 37.672 | 6.424 | .540 | 8580 |
| Beaver Creek-Liscom Creek | 12 | 31.435 | 28.487 | 34.532 | 7.962 | .492 | 8015 |
| Foster Creek | 3 | 31.113 | 21.740 | 33.251 | 7.89 | .767 | 7573 |
| Sand Creek | 2 | 31.835 | 28.055 | 33.435 | 6.615 | .300 | 7340 |
| **ROSEBUD COALBED** | | | | | | | |
| Colstrip | 16 | 21.168 | 29.107 | 38.852 | 9.541 | .823 | 8836 |
| Greenleaf Creek-Miller Creek | 4 | 27.175 | 26.143 | 37.491 | 8.592 | 1.169 | 8376 |
| Sarpy Creek Mine | Tipple | 25.000 | 29.000 | 37.000 | 9.000 | .330 | 8450 |
| Peabody Mine | Tipple | 26.300 | 28.600 | 34.700 | 10.400 | .750 | 8450 |
| Western Energy Mine | Tipple | 25.500 | 21.120 | 38.330 | 8.450 | .800 | 8750 |

**Table 4-12** Analyses of Coal Samples from the Pumpkin Buttes Coal Field, Dry Cheyenne, and Nearby Fields (Wegeman, Howell, and Dobin, 1928, p. 10).

| | Location | | | | Laboratory No. | Air-drying loss | Form of analysis | Moisture | Volatile matter | Fixed carbon | Ash | Sulphur | Heating value | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quarter | Sec. | T. N. | R. W. | | | | | | | | | Calories | British thermal units |
| Location 42 (Bed B) | SE. ¼ | 3 | 46 | 74 | 22973 | 21.7 | A | 31.0 | 30.5 | 28.4 | 10.1 | 1.4 | 4,022 | 7,240 |
| | | | | | | | B | 11.8 | 39.0 | 36.2 | 12.9 | 1.8 | 5,138 | 9,248 |
| | | | | | | | C | ........ | 44.2 | 41.1 | 14.7 | 2.1 | 5,827 | 10,489 |
| | | | | | | | D | ........ | 51.8 | 48.2 | ........ | 2.4 | 6,828 | 12,290 |
| Location 15 (Bed D) | NE. ¼ | 17 | 44 | 73 | 22904 | 25.3 | A | 35.5 | 30.5 | 29.7 | 6.2 | 1.2 | 4,082 | 7,348 |
| | | | | | | | B | 11.0 | 40.9 | 39.8 | 8.3 | 1.6 | 5,464 | 9,835 |
| | | | | | | | C | ........ | 45.9 | 44.8 | 9.3 | 1.8 | 6,141 | 11,054 |
| | | | | | | | D | ........ | 50.7 | 49.3 | ........ | 1.9 | 6,772 | 12,190 |
| Location 23 (Bed E) | NE. ¼ | 21 | 45 | 73 | 22885 | 20.3 | A | 29.0 | 32.0 | 31.1 | 7.8 | 1.4 | 4,564 | 8,215 |
| | | | | | | | B | 10.9 | 40.2 | 39.1 | 9.8 | 1.7 | 5,728 | 10,310 |
| | | | | | | | C | ........ | 45.1 | 43.9 | 11.0 | 2.0 | 6,428 | 11,570 |
| | | | | | | | D | ........ | 50.7 | 49.3 | ........ | 2.2 | 7,225 | 13,005 |
| Composite analysis of 5 samples of Roland coal bed at Peerless mines, 5½ miles east of Gillette. | ........ | ........ | ........ | ........ | A2965 | 17.8 | A | 33.0 | 29.7 | 31.5 | 5.8 | .5 | 4,311 | 7,760 |
| | | | | | | | B | 18.4 | 36.1 | 38.5 | 7.0 | .6 | 5,244 | 9,440 |
| | | | | | | | C | ........ | 44.3 | 47.1 | 8.6 | .8 | 6,433 | 11,580 |
| | | | | | | | D | ........ | 48.4 | 51.6 | ........ | .8 | 7,033 | 12,660 |
| Average of 20 samples from Sheridan Field | ........ | ........ | ........ | ........ | ........ | 10.4 | A | 23.3 | 32.2 | 41.1 | 3.5 | .3 | 5,194 | 9,350 |
| | | | | | | | B | 14.3 | 35.9 | 45.9 | 3.9 | .4 | 5,801 | 10,442 |
| | | | | | | | C | ........ | 41.9 | 53.6 | 4.6 | .5 | 6,771 | 12,188 |
| | | | | | | | D | ........ | 43.9 | 56.1 | ........ | .5 | 7,091 | 12,756 |
| Average of 5 samples from Douglas Field | ........ | ........ | ........ | ........ | ........ | 11.9 | A | 26.8 | 28.6 | 35.7 | 8.8 | .9 | 4,377 | 7,676 |
| | | | | | | | B | 16.9 | 32.5 | 40.6 | 10.0 | 1.0 | 4,972 | 8,970 |
| | | | | | | | C | ........ | 39.1 | 48.8 | 12.0 | 1.3 | 5,986 | 10,774 |
| | | | | | | | D | ........ | 44.2 | 55.6 | ........ | 1.4 | 6,806 | 12,254 |

**Table 4-13** Analyses of Coal Samples from the Glenrock Coal Field, Wyoming (Shaw, 1909, p. 162).

| Geologic formation | Fort Union (?). | | | | | | | | Montana. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name of coal zone | Douglas–Inez. | | | | Glenrock–Big Muddy. | | | | Resistant sandstone. | | Lowest. |
| Laboratory No | a 5318 | a 5317 | a 5321 | a 5422 | 5325 | 5326 | 5330 | 5322 | a 5320 | a 5323 | a 5319 |
| **Sample as received:** | | | | | | | | | | | |
| Prox. Moisture | 22.92 | 20.44 | 37.86 | 35.01 | 22.87 | 22.87 | 21.90 | 19.92 | 15.58 | 19.17 | 19.83 |
| Prox. Volatile matter | 42.62 | 30.49 | 29.08 | 28.46 | 48.03 | 33.89 | 34.05 | 49.25 | 23.28 | 26.17 | 41.39 |
| Prox. Fixed carbon | 22.25 | 18.68 | 22.37 | 28.82 | 20.54 | 36.71 | 37.38 | 20.25 | 22.68 | 17.54 | 26.21 |
| Prox. Ash | 12.21 | 30.39 | 10.69 | 7.71 | 8.56 | 6.53 | 6.67 | 10.58 | 38.46 | 37.12 | 12.57 |
| Ult. Sulphur | .58 | .43 | .35 | .28 | .52 | .97 | .86 | .68 | 1.17 | .52 | .72 |
| Ult. Hydrogen | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 5.39 | ...... | 3.85 | ...... |
| Ult. Carbon | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 51.96 | ...... | 30.68 | ...... |
| Ult. Nitrogen | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .60 | ...... | .56 | ...... |
| Ult. Oxygen | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 30.79 | ...... | 27.27 | ...... |
| Calories | 4,071 | 3,136 | 2,861 | 3,295 | 4,679 | 4,956 | 5,040 | 4,851 | 2,941 | 2,718 | 4,581 |
| British thermal units | 7,328 | 5,645 | 5,150 | 5,931 | 8,422 | 8,921 | 9,072 | 8,732 | 5,294 | 4,892 | 8,246 |
| Loss of moisture on air drying | 4.30 | 5.30 | 21.40 | 23.30 | 4.40 | 4.20 | 3.30 | 1.50 | 2.40 | 5.30 | 2.00 |
| **Air-dried sample:** | | | | | | | | | | | |
| Prox. Moisture | 19.46 | 15.99 | 20.94 | 15.27 | 19.32 | 19.49 | 19.23 | 18.70 | 13.50 | 14.65 | 18.19 |
| Prox. Volatile matter | 44.53 | 32.19 | 37.00 | 37.11 | 50.24 | 35.37 | 35.21 | 50.00 | 23.85 | 27.63 | 42.23 |
| Prox. Fixed carbon | 23.25 | 19.72 | 28.46 | 37.57 | 21.49 | 38.32 | 38.66 | 20.56 | 23.24 | 18.52 | 26.75 |
| Prox. Ash | 12.76 | 32.10 | 13.60 | 10.05 | 8.95 | 6.82 | 6.90 | 10.74 | 39.41 | 39.20 | 12.83 |
| Ult. Sulphur | .61 | .45 | .45 | .37 | .54 | 1.01 | .89 | .69 | 1.20 | .55 | .73 |
| Ult. Hydrogen | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 5.30 | ...... | 3.44 | ...... |
| Ult. Carbon | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 52.75 | ...... | 32.40 | ...... |
| Ult. Nitrogen | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .61 | ...... | .59 | ...... |
| Ult. Oxygen | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 29.91 | ...... | 23.82 | ...... |
| Calories | 4,254 | 3,312 | 3,640 | 4,296 | 4,894 | 5,173 | 5,212 | 4,925 | 3,013 | 2,870 | 4,675 |
| British thermal units | 7,657 | 5,961 | 6,552 | 7,733 | 8,810 | 9,312 | 9,382 | 8,865 | 5,424 | 5,166 | 8,414 |
| | *Ft. in.* | *Ft. in.* | *Ft. in.* | *Ft. in.* | *Ft. in.* | *Ft. in.* | *Ft. in.* | *Feet.* | *Feet.* | *Ft. in.* | *Feet.* |
| Thickness of coal bed | 1 10 | 4 2 | 1 8 | 2 6 | 3 6 | 4 8 | 5 6 | 6 | 3 | 1 10 | 3 |

a Weathered sample.

**Table 4-14** Analyses of Coal Samples from the Glenrock Coal Field (Glass, 1976).

*Badger coal bed:*

| As Received basis | Range (5 analyses) | Average |
|---|---|---|
| Moisture (%) | 22.7-29.3 | 27.4 |
| Volatile Matter (%) | 31.7-34.5 | 33.3 |
| Fixed Carbon (%) | 28.5-32.6 | 31.4 |
| Ash (%) | 6.6- 9.8 | 7.9 |
| Sulfur (%) | 0.4- 0.5 | 0.45 |
| Btu/pound | 7,606-8,290 | 7,951 |

*School coal bed:*

| As received basis | Range (3 analyses) | Average |
|---|---|---|
| Moisture (%) | 19.5-26.4 | 22.2 |
| Volatile Matter (%) | 34.4-38.1 | 35.9 |
| Fixed Carbon (%) | 28.3-33.6 | 30.5 |
| Ash (%) | 8.8-15.7 | 11.4 |
| Sulfur (%) | 0.5- 0.7 | 0.6 |
| Btu/pound | 7,830-8,870 | 8,183 |

*Glenrock- Big Muddy Zone coals:*

| As received basis | Range (10 analyses) | Average |
|---|---|---|
| Moisture (%) | 19.9-27.2 | 23.4 |
| Volatile Matter (%) | 29.7-49.3 | 35.9 |
| Fixed Carbon (%) | 20.3-41.3 | 34.0 |
| Ash (%) | 4.8-10.6 | 6.8 |
| Sulfur (%) | 0.40-0.97 | 0.66 |
| Btu/pound | 7,695-9,270 | 8,742 |

# 5. POTENTIAL METHANE RESOURCE

## 5.1 METHANE DATA IN EXISTING REPORTS

### 5.1.1 Methane Encountered in Shallow Drill Holes

Fifteen shallow drill holes or wells have been identified to date in Campbell County that contain anomalously large amounts of methane in product fluids. These holes were drilled either as water wells for local use or as shallow investigations of near-surface coalbeds (<500' depth); none were drilled for the much deeper-lying oil and gas deposits of the basin. Fourteen of these wells are in the Recluse area of northeastern Campbell County and define a northwest-southeast trending elliptical area approximately 33 miles long and 16 miles wide (Figure 5-1). The fifteenth well is separated from the above group by a distance of 50 miles; it lies to the south, 25.5 miles south of Gillette. Following is a brief description of these 15 holes.

Holes 1-7. Holes 1-7 were all drilled by the USGS in July and August of 1975 (Hobbs, 1978) to depths ranging between 400 and 500 feet (Figure 5-2). All holes were drilled to penetrate the Anderson and Canyon seams (splits of the Wyodak) and the Cook seam which underlies the Canyon. During drilling, methane content at the drill collar was measured with a hand-held methanometer. Essentially, methane was encountered in all seven holes, starting in sandstone beds just above the top coalbed, and continuing through all coalbeds and interlying sandstone-shale beds, to hole bottom. Methane in the gas flow at the collar ranged from as little as 0.1-0.2 percent in shale interbeds, to massive blowouts where gas flow rates were in excess of 1,000,000 cubic feet per day (cfd).

Some of the most pertinent data on individual wells are as follows. Hole 6 probably encountered the greatest concentrations of methane of any of the holes. Methane surges occurred when drilling through the Canyon seam and finally below the seam, at a depth of 325 feet, the hole blew out during core retrieval. Gas flow rate was estimated at 1,000,000 cfd, with the gas coming from a soft, poorly cemented sandstone. This occurred where methane content in the gas flow at the collar just prior to the blowout had been measured at 1 to 2 percent. The blowout continued for about one-half to one hour before water inflow to the hole stopped the gas flow. The hole was capped, and during a drawdown test several months later, all water pumped out was highly charged with methane.

Hole 5 blew out at two different depths--at about 190 feet below the Anderson seam, and at about 390 feet within the Canyon seam, near its base. Water inflow from the Anderson and Canyon seams, respectively, stopped both blowouts. Gas flow rates were estimated to be between 800,000 and 900,000 cfd. Especially important in this hole is the fact that the second blowout occurred within a major coal seam (the Canyon).

In Hole 2, methane concentrations up to 1 percent of the return air were measured in the lower 200 feet of hole. In Hole 1, during geophysical logging, gas flow out of the hole was very low, but methane content of the gas flowing registered the 60 percent maximum methanometer reading.

Holes 8-10. These three holes are listed in the report by Olive (1957) on the Spotted Horse Coal Field as shallow wells in which substantial gas flows were encountered. Though not specifically stated by Olive, it is presumed that these wells were water wells because of their shallow depths--total depths given for two of the wells being 245 and 415 feet. Olive states that ranchers in the area use sealed tanks for capture of the natural gas produced in their water wells--the gas being used for domestic and ranch-heating purposes.

For the above holes--8, 9 and lo--initial gas flow rate was 1,000,000, 1,000,000, and 500,000 cfd from depths of 225, 400, and 265 feet, respectively. Gas associated with other shallow water wells drilled into near-surface coal zones is also reported by Olive to occur in areas adjacent to Powder River and Clear Creek--the conflux of which is 25 miles to the northwest of Holes 8-10 and which lies to the west of the ellipse drawn on the map in Figure 5-l.

Hole 11. Hole 11 is a water well mentioned in Olive's report of the Spotted Horse Coal Field. This well, in the SE 1/4 sec. 30, T58N, R75W, was drilled for the Dobrenz ranch in 1916 and has been supplying by-product gas to the ranch since that time. Olive reported that gas pressure from the well was sufficient to lift a weight of 600 pounds (there is no mention, however, what pressure this force relates to). The Dobrenz ranch house's location is shown on Olive's geologic map of the Spotted Horse Field, which places the well in the center of a local structural low.

Hole 12. This is a well driven to provide water for the school at Recluse. The school building is shown on the 7-1/2' Recluse topographic quadrangle map as being one-half mile west of the hamlet of Recluse. We have not been able to determine any quantitative data on gas flow from the well, only that substantial gas flow was encountered. It was drilled by a local water-well driller and no geotechnical people were on site at the time.

Hole 13. Hole 13 is reported to have hit gas in or adjacent to the Canyon bed. This hole, drilled by local drillers with no geotechnical personnel in attendance, is about 7 miles northwest of Hole 6. The hole blew out, forming a surface crater 6 to 8 feet in diameter. Gas flow was so great that the only way it could be stopped was by pumping cement into the hole.

Hole 14. Hole 14 is a water well in section 7, T55N, R73W, where a large gas flow was encountered at 90 to 100 foot depth in a sandstone bed between the Smith and Anderson coalbeds.

Hole 15. Hole 15, is the USGS Hole No. US-754 (drilled in 1975). Bob Matson (Montana Geological Survey, personal communication) states that this hole was drilled with the intent of reaching the lower split of the Wyodak seam--the Canyon bed--but that they hit gas at 280 feet and were only able to drill another 10 feet and had to quit because of the large gas flow which blew the hole out. The hole had intersected coal at 100 feet (5 feet of coal) and at 180 feet (32 feet of coal--probably the upper split of the Wyodak, i.e., the Anderson seam). Hole location was the W 1/2, NW 1/4, Sec. 24, T46N, R71W (Neil Butte 7-1/2' quadrangle).

### 5.1.2 Methane in Artesian Wells

A large number of flowing artesian wells occur within the Powder River Basin. A number of these wells are known to contain substantial amounts of natural gas. Origin of this gas is the coalbeds and carbonaceous zones in the Fort Union Formation (Lowry and Cummings, 1966; Whitcomb, et al, 1966).

It was shown by Meinzer (1942) that gas in an aquifer increases the height to which water rises in a well and can create a flowing artesian well by raising the water to the surface. This lifting action is created by expansion of the gas as pressure is reduced in the water flowing from the aquifer. It is stated by Lowry and Cummings (1966) and Whitcomb, et al (1966) that, because of this lifting action, some portion of the artesian wells in the basin flow that would not otherwise do so.

Assuming that some significant--but as yet unknown--portions of the flowing artesian wells, are flowing because they are tapping coalbeds with anomalously high methane content, such artesian wells might be a useful exploration aid. Hydrologic maps covering the Powder River Basin show locations of at least 198 flowing artesian wells within the boundary of the Fort Union Formation. Distribution of these 198 wells is shown on the map of Figure 5-3. This map indicates a non-random distribution of the wells with 68 being in the eastern half of Sheridan County, 71 in northeastern Johnson County, 29 in the northern half of Campbell County, and 16 located mostly in two separate areas in Converse County. Of the flowing artesian wells in Sheridan and Johnson Counties, at least five are known to contain methane (Table 5-1, Figure 5-3). The area of northern Campbell County with anomalously large numbers of flowing artesian wells also coincides with the elliptical area around Recluse that contains the 14 shallow drill holes in which anomalously large quantities of methane were encountered (Section 5.1.1).

Of the flowing artesian wells in Sheridan, Johnson, and northern Campbell Counties, most are located along the major drainages of Tongue River, Powder River, and two principal tributaries of the Powder--Little Powder River and Clear Creek (Figure 5-3). A secondary zone of occurrences comprises a narrow belt along the western margin of the Fort Union Formation, extending from north of Tongue River to south of Clear Creek (Figure 5-3). Reason for apparent concentration of flowing wells along the main drainage channels is probably threefold:

(1) Concentration of rural development (and wells) along river alluvial flats

(2) Lower well-head elevations along river channels than on the intervening ridges, and

(3) Possible concentration of free methane in coalbed open fractures along the structurally controlled major drainage channels.

Location of four of the flowing artesian wells, known to contain methane, along the Powder River south from Clear Creek, and one well near the Tongue River provides tentative evidence that reason number three above, is real, i.e., that free methane is more abundant in fractured coal-bearing strata adjacent to structurally controlled drainage channels than it is in land areas between such channels.

### 5.1.3 Possible Structural and Stratigraphic Controls of Methane in Coalbeds

All data collected to date have indicated that the Powder River Basin should provide several favorable target areas for recovery of methane gas from coalbeds by use of shallow drill holes. The basin is one of the largest coal-bearing basins in the West and has the largest reserves of coal of any basin or region of the U.S., 1.3 trillion tons. Coal in the basin is mostly in thick beds, all within potentially economic drilling depths, the deepest coalbeds being at 2500 feet in the basin center. Tertiary structure of coal-bearing formations in the basin is relatively simple, comprising a generally northwest-southeast trending gentle asymmetrical syncline lying between the Black Hills Uplift on the east and the Bighorn Mountains on the west (Figure 3-12). Because the synclinal axis lies close to the western margin of the shallow basin, dips on the eastern limb are quite low, averaging less than $1^{o}$. Superimposed on this simple basin structure is a fracture system which generally comprises two fracture sets that control local surface drainage and topography. The dominant fracture set parallels the northwest-southeast trend of the basin axis, the secondary fracture set being approximately perpendicular to the basin axis. Roughly concordant with the northwest-southeast and northeast-southwest trends of the two fracture sets is a system of very local small synclinal-anticlinal folds that seem to be confined stratigraphically to the coal-bearing zones within the Fort Union and Wasatch Formations. These local folds are probably syngenetically related to the original deposition of the sediments. That is, they may in part have been "draped" over topographic undulations on the depositional surface and in part caused by slumping of saturated sediments on shallow basin slopes prior to lithification. It is the resulting small but numerous anticlinal highs that seem such promising specific targets for collecting any methane adsorbed within Fort Union and Wasatch coalbeds, as in the Spotted Horse and Sheridan Fields, Wyoming, and northern extension of the Sheridan Field in Montana (Figures 5-4 to 5-8).

Coal in the Paleocene Fort Union Formation and the immediately overlying Eocene Wasatch Formation occurs in at least 18 stratigraphically separable beds. Because the basin is so large and the study of subsurface coal relationships so limited, correlation of coalbeds from place to place in the basin is still uncertain. What is known, though, is that the basin contains the greatest concentration of thick coalbeds in the nation. In at least three centers of deposition within the basin, individual coalbeds are coalesced into massive "superbeds." These three centers are:

1. A 20-square-mile area just west of the Decker Mine, Big Horn County, Montana, where the Anderson, Dietz No. 1, and Dietz No. 2 coal seams are coalesced into a bed 80 feet thick.

2. A north-south trending belt approximately 15 miles long and 1 to 2 miles wide at Lake De Smet, Sheridan County, Wyoming, where five coal seams are coalesced into a bed whose thickness ranges from 70 to more than 220 feet. This combined bed--now called the Lake De Smet Bed--is the thickest known coalbed in the U.S. and thought to be the second thickest in the world.

3. The area surrounding Gillette, Campbell County, Wyoming, where the Anderson, Canyon "A", and Canyon "B" seams coalesce into a single bed (the "Wyodak" or "Anderson Wyodak") ranging in thickness from 70 to more than 125 feet.

The methane recovery target area at Recluse defined by drill holes 1 through 14 (discussed in Section 5.1.1) occurs at the margin of one of these depositional centers where a superbed splits into two or more component seams; that is, at the northern margin of the Wyodak superbed centered on Gillette. Hole 15 lies just to the south of the Gillette depositional center. At such locations, it may be that methane gas release from the coal seams, and collection within interbedded coal seam and porous sandstone sequences, may be optimal. Identification of such natural gas collection traps should be useful for indicating areas within the Powder River Basin where underlying coalbeds could have anomalously large amounts of adsorbed methane.

In the Recluse area (Hobbs, 1978), the apparent preferential sequence of individual coal and sandstone beds for production of methane from the shallow wells drilled is:

1. The sandstone beds between the Anderson and Canyon bed(s),
2. The Canyon coalbeds,
3. The Sandstone bed below the Canyon,
4. The sandstone sequence between the Canyon coalbeds, and
5. The Anderson coalbed.

Shallow drill hole data in the Recluse area indicate that coalbeds and porous sandstone sequences interbedded with and closely overlying the coalbeds all act as reservoirs for methane desorbed from the coal as well as reservoirs for ground water. Though poorly cemented, highly porous sandstone beds seem to be the most efficient reservoirs in the Recluse area coal-zone sequence; the coalbeds themselves are also good to excellent reservoirs. In the sequence preference given in the preceding paragraph, the deeper coalbed--the Canyon-- seems to be the best coal reservoir.

In Figures 5-4 to 5-8, representative areas in Campbell and Sheridan Counties, Wyoming, and Big Horn County, Montana, are shown which contain possible structural and stratigraphic traps in which methane associated with coal-bearing strata could collect. In Figure 5-4 to 5-6, a number of closures on structural highs are identified which are promising methane drilling targets. In Figure 5-4, six such highs are identified in the Recluse area of Campbell County that are in close association to five of the shallow drill holes that contained large amounts of methane (discussed in Section 5.1.1). In Figure 5-5, 18 such highs are identified, four of which are along the sinuous axis connecting a series of anticlinal folds, just south of, and subparallel to, the Powder River. Just to the north of this line of anticlinal highs is the Dobrenz Ranch water well which has been producing by-product methane since 1916. It is of extreme interest that this well is in the center of a shallow structural low. This may indicate that coal-bearing strata subjected to tensional stresses along fold axes--including both synclinal and anticlinal folds--may be sufficiently fractured in the central Powder River Basin to act as collecting zones for free methane desorbed from coal-particle surfaces. In Figure 5-6, three more such structural highs are shown aligned along a NW-SE trending anticlinal axis in the Clear Creek area, east of Lake De

Smet and Buffalo. In Figures 5-7 and 5-8, two possible methane drilling targets are shown in the area northwest of the Decker Mine, Big Horn County, Montana. One target is a structural high in the superbed represented by the coalesced Anderson-Dietz No. 1-Dietz No. 2 coalbeds. The other target is a possible stratigraphic trap where the above superbed splits into two beds. Methane desorbed from the coalbeds could be entrapped within porous sandstones between the two thick coalbeds.

## 5.2 METHANE RECOVERY FROM COALBEDS PROJECT DATA

No data have been obtained from the Powder River Basin, as yet, in the Methane Recovery from Coalbeds Project. The only two drill core coal samples collected to date for determination of adsorbed methane are from the Recluse area. Desorption tests on these samples indicated only a small methane content of the samples, about 8-9 c.f. per ton of coal (Hobbs, 1978). We strongly suspect that the gas remaining in these samples at the time of testing had little relationship to methane contained in the coalbeds in place. The samples were from the Canyon and Cook coal seams collected at depths of approximately 375 feet. Coals of the Spotted Horse Field range in rank mostly between lignite and subbituminous C. Because of their low rank and never having been buried much, if any, deeper than their present shallow depths, the coals are very porous. Thus, any coal samples probably will lose almost all adsorbed methane very quickly--i.e., during drilling and retrieval, prior to placing of the samples in sealed canisters at the surface.

## 5.3 ESTIMATED RESOURCE VOLUME

There is no quantitative data available on the specific amount of methane present in coalbeds of the Powder River Basin. As stated previously, the in-place methane is thought to be much higher than that indicated in desorption analyses. This may, in part, be due to the low rank, shallow depth and relative high porosity of coals of the Powder River Basin.

With estimates of the total coal resource for various beds and areas in the Powder River Basin, it is possible to present reasonable estimates of expected in-place methane resource.

Elmer Schell, based on a USGS drilling program, estimates the total coal resource of the Powder River Basin to be 1.3 trillion tons. Glass (1976) and Mapel and Swanson (1977) give more conservative estimates for the Wyoming and Montana portions of the basin totalling 788 billion tons. Using these figures as high and low estimates respectively, for the total coal resource of the basin, we assume that approximately half of the coal would not be amenable to methane drainage, possibly because of shallow depth, or discontinuous nature of the coalbeds. That means that between 394 billion and 650 billion tons of coal might be available in the Powder River Basin for methane recovery.

A reasonable estimate for the minimum average in-place methane content of the coalbeds of the basin is about 15 cubic feet per ton of coal. This is twice the amount indicated in measured desorbed gas in three near-surface coal cores. It is believed that prime methane target areas--as outlined previously--and deeper coals will contain substantially greater concentrations of methane. Table 5-2 presents estimates of the total methane resource of the Powder River Basin, as well as the methane resource of the Wyodak coalbed--the largest single coalbed in the U.S.

| Coal Bed or Area | Assumed Coal Resource (tons) | Gas Resource in Cubic Feet | | | |
|---|---|---|---|---|---|
| | | @15 cu ft/ton | @25 cu ft/ton | @50 cu ft/ton | @100 cu ft/ton |
| Powder River Basin[1] | **6.50** x $10^{11}$ | 9.75 x $10^{12}$ | 1.63 x $10^{13}$ | **3.25** x $10^{13}$ | **6.50** x $10^{13}$ |
| Powder River Basin [2] | 3.94 x 10” | 5.91 x $10^{12}$ | 9.85 x $10^{12}$ | 1.97 x $10^{13}$ | 3.94 x $10^{13}$ |
| Wyodak - Anderson coal bed [3] | 1.00 x $10^{11}$ | 1.50 x 10” | **2.50** x $10^{12}$ | **5.00** x $10^{12}$ | 1.00 x $10^{13}$ |

[1] ½ of Elmer Schell's (USGS) coal resource estimate of 1.3 trillion tons

[2] ½ of combined coal resource estimate of Glass (1976) and Mapel and Swanson (1977) of 788 billion tons

[3] total estimate of coal resource of Wyodak-Anderson coal bed (Averitt, 1975)

**Table** 5-2 Estimated in Place Methane Resource, Powder River Basin

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 6.1 CONCLUSIONS

The Powder River Basin of Wyoming and Montana presents an unusually promising opportunity for collecting large amounts of methane gas from relatively shallow coalbeds. The basin is very large and contains the greatest concentration of thick coalbeds in the nation. Though the coals are of low rank, which normally indicates small amounts of adsorbed methane per unit volume of coal, the great thickness of many of the coal seams indicate large volumes of methane contained per unit area of coalbed. In addition to great thickness for individual seams, the basin is noted for the large number of thick seams that are intercepted by a single drill hole at shallow depths. For example, a single drill hole in Campbell County, Wyoming, intercepts 16 coalbeds greater than 5 feet thick, of which 10 beds are greater than 20 feet thick and one is greater than 60 feet thick (375 feet of coal within 2500 feet of the surface; Apache-l Geer wildcat well; Sec. 31, T47N, R73E). Because of the high porosity of these low-rank coals and the great total thickness of coal encountered at shallow depths, large amounts of methane should be recoverable per unit length of drill hole.

It is important to determine if methane gas can be practicably collected from shallow Powder River coalbeds as quickly as possible. It is these coalbeds that are the principal target of the great strip mines being put into operation along the northwestern and entire eastern rim of the basin. As these pits are opened, any methane contained within and adjacent to stripping areas will be lost to the atmosphere. Thus, if such methane gas is to be salvaged, it must be done before new pits are opened and the entire rim of the Powder River Basin coalbeds is exposed to updip migration of methane contained in the deeper, more central portion of the basin.

The area that we consider the prime methane exploration target within the Powder River Basin is outlined in Figure 6-l. This area encompasses portions of Campbell, Sheridan, and Johnson Counties in Wyoming and Big

Horn and Powder River Counties in Montana. Factors used in delimiting the boundaries of this target area include:

1. Restricting the area to lands underlain by the Tongue River Member of the Fort Union Formation, and additionally to

2. Areas in which shallow drill holes are known to flow anomalously large amounts of methane,

3. Areas in which flowing artesian wells are concentrated, or

4. Areas in which three or more individually thick coalbeds are coalesced together into a single superbed.

Within the regional target delimited on the map of Figure 6-1, smaller initial target areas can be defined based on probable structural and stratigraphic controls, including the following:

a. Major drainage channels that parallel any of the known fracture sets, especially those channels along which flowing artesian wells are concentrated. Included principally are Tongue River, Little Powder River, and especially Powder River and Clear Creek. These drainages probably are fault-, or at least fracture-controlled. Coal-bearing strata, along and adjacent to these channel ways, are probably fractured to a greater degree and should contain more free methane than rocks, away from the channel ways.

b. Secondary channel ways with anomalously linear development parallel to the major, NW-SE or NE-SW fracture-set directions and along which are located flowing artesian wells or shallow-drill holes known to emit methane. An example is Hay Creek, southeast Of Recluse, which follows an extremely straight NW-SE trending path and along which is 1 ocated a 245-foot deep hole which had an initial gas emission rate of a million cubic feet per day (Hole 8, Figure 5-l).

c. Zones along anticlinal fold axes, where rocks under tensional stress could be more highly fractured than rocks on fold limbs. Anticlinal crests present highly favorable zones where fractured rocks can act as hosts for methane migrating updip from coalbeds along fold limbs.

d. Zones along synclinal fold axes where methane desorbed from coal-particle surfaces can collect in-place in open fractures along the stressed rocks.

e. Stratigraphic traps created where superbeds split into two or more individual coalbeds. An example is the area northwest of the Decker Mine, Big Horn County, Montana, where the Anderson splits from the Dietz No. 1 and No. 2 coalbeds (area B, Figure 5-7).

f. Coalbeds in the deeper portion of the basin, paralleling the basin synclinal axis. Adsorbed methane concentration should be greatest in such beds because of the greater hydrostatic pressure and the probable higher coal rank in the more deeply buried coals.

g. The northwest-trending, 33-mile long, elliptical area in Campbell County in which shallow drill holes flowing methane gas are concentrated (Figure 5-1). Geologic controls for this concentration probably are partly structural and partly stratigraphic.

Initial individual drill sites for collecting coalbed methane data could include:

a. Sites beside holes known to flow methane or beside flowing artesian wells containing methane.

b. Sites on the crests of small structural closures along fold axes.

c. Sites at the intersections of two or more favored linear structural features, e.g., the intersection of a fold axis and a linear stream channel or the intersection of two linear stream channels such as the conflux of Powder River and Clear Creek.

## 6.2 RECOMMENDATIONS

An initial program here recommended for investigating methane recovery potential of the Powder River Basin includes:

1. Construction of a lineation map of the basin from topographic and geologic maps, from spacecraft synoptic imagery, and from aerial photographs.

2. Collection of all data possible from the literature, from geotechnical personnel currently working in the basin, and from local water-well drillers, pertaining to methane content encountered in drill holes and water wells.

3. Field measurement of fracture systems in coal-bearing strata of the central Powder River Basin.

4. Collection of well-bottom samples from both flowing and non-flowing artesian wells in the central Powder River Basin and measurement of contained methane.

5. Cooperating with the U.S. and Montana geologic surveys in collection of coal core samples in their shallow-to-intermediate depth drilling programs (generally less than 1000-foot depths) and performing methane desorption tests.

6. Performing "piggyback" tests with companies exploring for oil and gas and for uranium in collection of coal core samples for methane desorption tests.

7. Performing intermediate-to-long term gas-flow tests on selected shallow holes drilled either for the U.S. or Montana Geological Survey programs or drilled specifically for the Methane Recovery from Coalbeds Project. This task is especially important for the Powder River Basin because the low-rank coal samples collected by coring may be so porous as to essentially lose all adsorbed methane before the samples can be placed in sealed canisters at the surface.

8. Drilling small anticlinal highs--locate three to five dewatering wells at base of high and methane production well on top of high.

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Wyoming Geological Association, 1971, Twenty-third Annual Field Conference Guidebook: Symposium on Wyoming Tectonics, 187 p.

Wyoming Geological Association, 1976, Geology and energy resources of the Powder River: 28th Annual Field Conference Guidebook, 328 p.

Wyoming Geological Association, Symposium Committee, 1957, Wyoming oil and gas field symposium, 1957: Casper, Wyoming, Wyoming Geol. Assoc., 484 p.

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APPENDIX A

TOPOGRAPHIC AND LAND OWNERSHIP MAPS COVERING THE POWDER RIVER BASIN

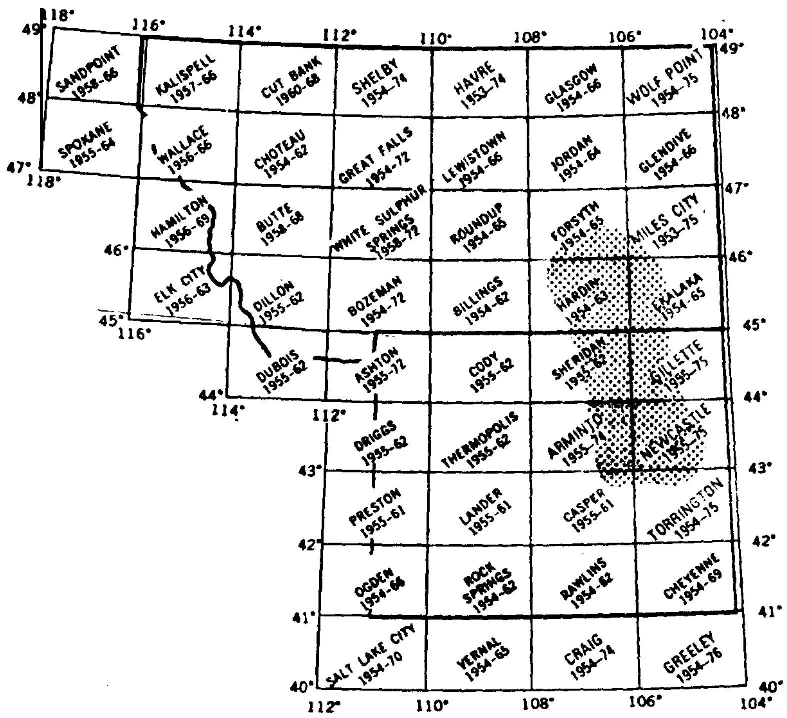


**Figure A-1** U.S.G.S. Index to Topographic Maps, Scale 1:250,000

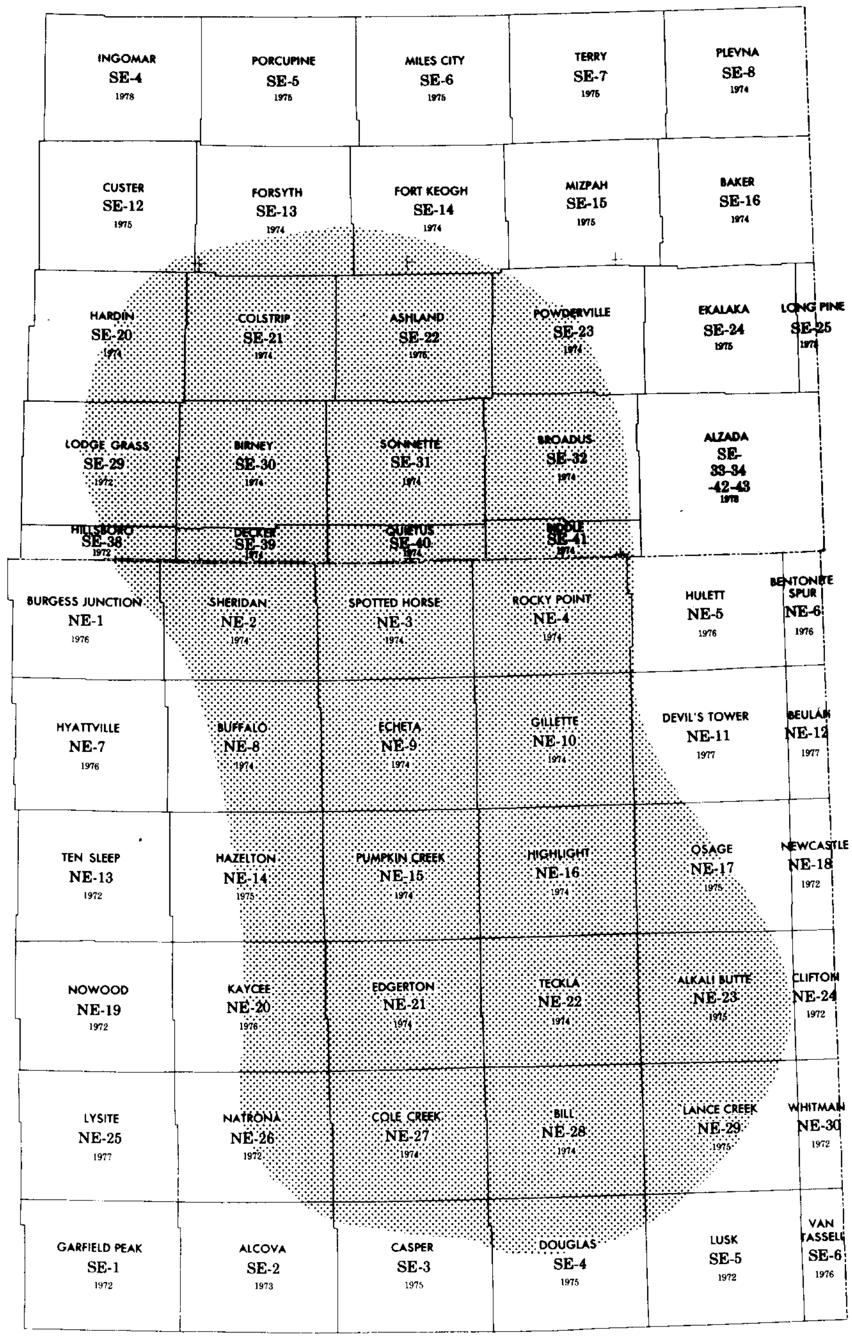


**Figure A-4** Index to Bureau of Land Management Maps Covering Powder River Basin Showing Land and Mineral-Rights Ownership of the Federal Government.

APPENDIX B

REFERENCES TO GEOLOGIC MAPPING IN THE POWDER RIVER BASIN AS INDEXED BY THE U.S. GEOLOGICAL SURVEY (Up to 1970)

The reference lists in this section (B-l through B-4) refer to mapping in the Powder River Basin and are taken from four separate U.S. Geological Survey State index maps, which are out of print, but available in most libraries. The numbers preceeding each reference are keyed to the map areas outlined on the index maps. Updated index maps for Montana and Wyoming are included in the pocket of this report.

B-l REFERENCES TO GEOLOGIC MAPPING, POWDER RIVER BASIN, MONTANA, 1859-1954

1. 1859. Hayden, F.V., Geological sketch of the estuary and fresh water deposits of the Badlands of the Judith, with some remarks upon the surrounding formations: Am. Philos. Soc. Trans., n. s., v. 11, p. 123-138. Pl. 8, 1:1,500,000.

8. 1894. Eldridge, G.H., Geologic reconnaissance in northwest Wyoming: U.S.G.S. Bull. 119. Pl. 1, 1:750,000.

24. 1905. Darton, N.H., Geology and underground water resources of the central Great Plains: U.S.G.S. Prof. Paper 32. Pl. 35, 1:1,250,000.

27. 1906. Darton, N.H., Geology of the Bighorn Mountains: U.S.G.S. Prof. Paper 51. Pl. 47, 1:250,000.

28. 1906. Darton, N.H., Fish remains in Ordovician rocks in Bighorn Mountains, Wyo., With a resume of Ordovician geology of the Northwest: Geol. Soc. America Bull., v. 17, p. 541-566. Pl. 73, 1:1,000,000.

48. 1910. O'Harra, C.C., Badland formations of the Black Hills region: South Dakota School of Mines Bull. 9. Pl. 2, 1:1,250,000, chiefly from map by N.H. Darton as modified by W.D. Matthew and Albert Thomson.
1920. O'Harra, C.C., White River badlands: South Dakota School of Mines Bull. 13. Pl. 2, 1:1,500,000, chiefly from map by N.H. Darton as modified by W.D. Matthew and Albert Thomson.

79. 1915. Campbell, M.R., and others, Guidebook of the western United States, pt. A, Northern Pacific Route: U.S.G.S. Bull. 611. Sheets 10-20, 1:500,000.

115. 1923. Rogers, G.S., and Lee, Wallace, Geology of the Tullock Creek coal field, Rosebud and Big Horn Counties: U.S.G.S. Bull. 749. Pl. 10, 1:125,000, G.S. Rogers, Wallace Lee, and H.M. Robinson.

130. 1929. Baker, A.A., Northward extension of the Sheridan coal field, Big Horn and Rosebud Counties: U.S.G.S. Bull. 806-B, p. 15-67. Pls. 28 and 29, 1:62,500.

132. 1929. Hall, G.M., and Howard, C.S., Ground Water in Yellowstone and Treasure Counties: U.S.G.S. Water-Supply Paper 599. Pl. 7, 1:250,000.

133. 1929. Renick, B.C., Geology and ground-water resources of central and southern Rosebud County: U.S.G.S. Supply Paper 600. Pl. 1, 1:250,000 and fig. 15, 1:160,000.

135. 1930. Dobbin, C.E., Forsyth coal field, Rosebud, Treasure, and Big Horn Counties: U.S.G.S. Bull. 812, p. l-55. Pl. 7, 1:125,000.

137. Robinson, C.S., Mapel, W.J., and Bergendahl, M.H., 1964, Stratigraphy and structure of the northern and western flanks of the Black Hills uplift, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Prof. Paper 404. Pl. 1, 1:96,000.

Mapel, W.J., Robinson, C.S., and Theobald, P.K., 1959, Geologic and structure contour map of the northern and western flanks of the Black Hills, Wyo., Mont., and S. Dak.: U.S. Geol. Survey Oil and Gas Inv. Map OM-191. 1:96,000.

142. 1931. Perry, E.S., Ground water in eastern and central Montana: Montana Bur. Mines and Geology Mem. 2. Pl. 6, 1:1,500,000.

143. 1932. Bass, N.W., Ashland coal field, Rosebud, Powder River, and Custer Counties: U.S.G.S. Bull. 831-B, p. 19-105. Pl. 3, 1:62,500.

162. 1935. Perry, E.S., Geology and ground-water resources of southeastern Montana: Montana Bur. Mines and Geology Mem. 14. (a) Pl.3, 1:750,000, (b) fig. 20, 1:750,000.

1937. Perry, E.S., Natural gas in Montana: Montana Bur. Mines and Geology Mem. 3. (b) Pl. 6-A, 1:750,000.

165. 1936. Pierce, W.G., Rosebud coal field, Rosebud and Custer Counties: U.S.G.S. Bull. 847-B, p. 43-120. Pl. 11, 1:62,500.

192. 1940. Parker, F.S., and Andrews, D.A., Mizpah coal field, Custer County: U.S.G.S. Bull. 906-C, p. 85-133. Pl. 16, 1:62,500.

254. 1951. Richards, P.W., and Rogers, C.P., Jr., Geology of the Hardin area, Big Horn and Yellowstone Counties: U.S. Oil and Gas Investig. map OM 111. Sheet 1, 1:62,500, P.W. Richards, C.P. Rogers, Jr., Z.S. Altschuler, and others.

267. 1952. Bryson, R.P., Coalwood coal field, Powder River County: U.S.G.S. Bull. 973-B, P. 23-106. Pl. 1, 1:63,360, from field work of R.P. Bryson, W.H. Hass, R.M. Neuman, and others.

B-2 REFERENCES TO GEOLOGIC MAPPING, POWDER RIVER BASIN, MONTANA, 1955-1967

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Richards, P.W., 1955, Geology of the Bighorn Canyon -- Hardin area, Montana and Wyoming: U.S. Geol. Survey Bull. 1026. Pl. 1, 1:62,500.

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Everhart, D.L., 1956, Tectonic control of uranium deposition in the Rocky Mountain region, in Am. Assoc. Petroleum Geologists Rocky Mtn. Sec., Geological record, Feb. 1956, P. 87-97. Fig. 4, 1:125,000 (scale and outline approximate). Also small-scale map, fig. 2.

42. Warren, W.C., 1959, Reconnaissance geology of the Birney-Broadus coal field, Rosebud and Powder River counties, Mont.: U.S. Geol. Survey Bull. 1072-J. Pl. 19, 1:63,360.

51. Moulder, E.A., Klug, M.F., Morris, D.A., and Swenson, F.A., 1960, Geology and ground-water resources of the lower Little Bighorn River Valley, Big Horn County, Mont.: U.S. Geol. Survey Water-Supply Paper 1487. Pls. 1, 2, 3, and 4, 1:32,000.

162. Bryson, R.P., and Bass, V.W., 1966, Geologic map and coal sections of the Moorhead coal field, Montana: U.S. Geol. Survey open-file rept. Figs. 1 and 2, 1:63,360 (Fig. 3, explanation.)

13. 1894. Eldridge, G.H., Geological reconnaissance in northwest Wyoming: U.S.G.S. Bull. 119. Pl. 1, 1:750,000.

16. 1897. Scott, Samuel, Map of the Black Hills of South Dakota and Wyoming, Custer City, S. Dak., 1:316,800.

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27. 1903. Richardson, G.B., Upper red beds of the Black Hills: Jour. Geology, v. 11, p. 365-393. Map, 1:1,250,000, N.H. Darton and G.B. Richardson.

35. 1906. Darton, N.H., and Salisbury, R.D., Cloud Peak-Fort McKinney quadrangles: U.S.G.S. Geol. Folio 142. Maps, 1:125,000, N.H. Darton, E.S. Bastin, and Eliot Blackwelder.

36. 1906. Darton, N.H., Geology of the Bighorn Mountains: U.S.G.S. Prof. Paper 51. (a) Pl. 47, 1:250,000, (b) pl. 26 (glacial geology), 1:125,000, Eliot Blackwelder and E.S. Bastin.

1916. Lupton, C.T., and Condit, D.D., Gypsum in the southern part of the Bighorn Mountains: U.S.G.S. Bull. 640, p. 139-147. (a) Pl. 3, 1:937,500, mainly after maps by N.H. Darton and C.A. Fisher.

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48. 1909. Darton, N.H., Geology and water resources of the northern portion of the Black Hills and adjoining regions: U.S.G.S. Prof. Paper 65. Pl. 4, 1:250,000.

49. 1909. Taff, J.A., Sheridan coal field: U.S.G.S. Bull. 341, p. 123-150. Pl. 8 (coal outcrops), 1:250,000, J.A. Taff, A.W. Thompson, and F.H. Kay.

50. 1909. Shaw, E.W., Glenrock coal field: U.S.G.S. Bull. 341, p. 151-164. Pl. 9, 1:250,000, E.W. Shaw and C.T. Lupton.

60. 1910. Stone, R.W., and Lupton, C.T., Powder River coal field, adjacent to the Burlington Railroad: U.S.G.S. Bull. 381, p. 115-136. Pl. 8, 1:250,000.

61. 1910. Gale, H.S., and Wegemann, C.H., Buffalo coal field: U.S.G.S. Bull. 381, p. 137-169. (a) Pl. 10, 1:250,000, (b) pl. 11, 1:63,360.

69. 1912. Wegemann, C.H., Powder River coal fleld: U.S.G.S. Bull. 471, p. 56-75. Pl. 7, 1:63,360.

70. 1912. Davis, J.A., Little Powder River coal field, Campbell County: U.S.G.S. Bull. 471, P. 423-440. Pl. 34, 1:125,000.

71. 1912. Wegemann, C.H., Sussex coal field, Johnson, Natrona, and Converse Counties: U.S.G.S. Bull. 471, p. 441-471. (a) pl. 35, 1:500,000, (b) fig. 10, 1:62,500 (c) pl. 36, 1:62,500, (d) pl. 38, 1:62,500, (e) pl. 39, 1:62,500, (f) pl. 41, 1:62,500, (g) pl. 42, 1:125,000.

72. 1912. Winchester, D.E., Lost Spring coal field, Converse County: U.S.G.S. Bull. 471, P. 472-515. (a) pl. 44, 1:62,500, (b) pl. 45, 1:125,000.

79. 1913. Wegemann, C.H., Barber coal field, Johnson County: U.S.G.S. Bull. 531, P. 263-284. pl. 19, 1:62,500.

80. 1913. Trumbull, L.W., Prospective oil fields at Upton, Weston County, Buck Creek, Niobrara County, Rattlesnake Mountains, Natrona County, La Barge, Lincoln County: Wyoming Geol. Survey Bull. 5. (a) pl. 2, 1:50,000, (b) pl. 3, 1:187,500, (c) pl. 4, 1:250,000, (d) pl. 5, 1:125,000.

86. 1915. Barnett, V.H., Possibilities of oil in the Big Muddy dome, Converse and Natrona Counties: U.S.G.S. Bull. 581, p. 105-117. pl. 4, 1:125,000.

93. 1916. Spencer, A.C., Atlantic gold district and the North Laramie Mountains, Fremont, Converse, and Albany Counties: U.S.G.S. Bull. 626. (a) Pl. 1, 1:78,125; (b) pl. 4, 1:437,500, N.H. Darton and others; (c) fig. 3, 1:93,750; (d) fig. 4, 1:18,000; (e) fig. 5, 1:18,000; (1) fig. 6, scale not given.

96. 1916. Condit, D.D., Relations of the Embar and Chugwater formations in central Wyoming: U.S.G.S. Prof. Paper 98, p. 263-270. pl. 61, 1:1,000,000.

82. 1914. Barnett, V.H., Douglas oil and gas field, Converse County: U.S.G.S. Bull. 541, P. 49-88. pl. 4, 1:125,000.

101. 1918. Wegemann, C.H., Salt Creek oil field: U.S.G.S. Bull. 670. (a) pl. 1, 1:62,500, (b) pl. 2, 1:16,000.
1911. Wegemann, C.H., Salt Creek oil field: U.S.G.S. Bull. 452, p. 37-83. (a) pl. 7, 1:63,360.

116. 1920. Hancock, E.T., Lance Creek oil and gas field, Niobrara County: U.S.G.S. Bull. 716, p. 91-122. Pl. 10, 1:62,500.

117. 1920. O'Harra, C.C., White River badlands: South Dakota School of Mines Bull. 13. Pl. 2, 1:1,500,000, chiefly from map by N.H. Darton as modified by W.D. Matthew and Albert Thomson.
1910. O'Harra, C.C., Badland formations of the Black Hills region: South Dakota School of Mines Bull. 9, 1910. Pl. 2, 1:1,250,000.

121. 1923. Collier, A.J., Osage oil field, Weston County: U.S.G.S. Bull. 736, p. 71-110. Pl. 13, 1:62,500.

126. 1924. Collier, A.J., and Boyer, W.W., North Casper Creek anticline: U.S.G.S. Press release 16846. Map, 1:125,000.

127. 1924. Rubey, W.W., Rocky Point anticline: U.S.G.S. Press release 24421. Map, 1:125,000.

140. 1928. Wegemann, C.E., Howell, R.W., and Dobbin, C.E., Pumpkin Buttes coal field: U.S.G.S. Bull. 806-A, p. l-14. (a) Pl. 2, 1:126,720, (b) pl. 3, 1:126,720, C.E. Wegemann and C.E. Dobbin.

138. 1928. Dobbin, C.E., and Barnett, V.H., Gillette coal field, northeastern Wyoming: U.S.G.S. Bull. 796, p. l-50. (a) Pls. 9 and 10, 1:125,000, (b) pl. 12, 1:62,500.

146. 1929. Southeastern Wyoming and adjoining parts of northeastern Colorado: Kansas Geol. Soc. 3d annual field conference guidebook. Map, 1:500,000, B.B. Thomas, from U.S.G.S. maps and other sources.

152. 1931. Thorn, W.T., Jr., and Spieker, E.M., Significance of geologic conditions in Naval Petroleum Reserve No. 3: U.S.G.S. Prof. Paper 163. Pl. 7, 1:21,120.

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204. 1940. Dorf, Erling, relationship between floras of the type Lance and Fort Union formations: Geol. Soc. America Bull., v. 51, p. 213-235. Fig. 1, 1:187,500.

229. 1943. Kramer, W.B., and Dobbin, C.E., Geologic map and sections of the Lance Creek oil and gas field and vicinity, Niobrara County: U.S.G.S. map, 1:63,360.

246. 1946. Hares, C.J., Geologic map of the southeastern part of the Wind River Basin and adjacent areas in central Wyoming: U.S.G.S. Oil and Gas Investig. Prelim. Map 51, 1:125,000.

254. 1947. Horn, G.H., Geologic and structure contour map of the Mush Creek area, Weston County: U.S.G.S. map, 1:62,500.

260. 1948. Sharp, R.P., Early Tertiary fanglomerate, Big Horn Mountains: Jour. Geology, v. 56, p. l-15. Fig 3, 1:250,000, modified from maps by N.H. Darton and Max Demorest.

264. 1948. Shade, N.R., Geophysical history of the Cole Creek oil field near Casper: Geophysical case histories, v. 1, p. 503-511. Fig. 2, 1:500,000.

269. 1949. Dobbin, C.E., and Horn, G.H., Geology of the Mush Creek and Osage oil Fields and vicinity, Weston County: U.S.G.S. Oil and Gas Investig. Prelim. Map 103, 1:125,000, partly from published maps.

286. 1951. Love, J.D., and Weitz, J.L., Geologic map of the Powder River Basin and adjacent areas: U.S.G.S. Oil and Gas Investig. Map OM 122, 1:312,500.

298. 1952. Love, J.D., Preliminary report on uranium deposits in the Pumpkin Buttes area, Powder River Basin: U.S.G.S. Circ. 176. (a) Fig. 2, 1:312,500, (b) Pl. 1, 1:62,500.

299. 1952. Towse, Donald, Frontier formation, southwest Powder River Basin: Am. Assoc. Petroleum Geologists Bull., v 36, p. 1962-2010. Figs. 2 and 3, 1:1,000,000.

303. 1953. Olive, W.W., Spotted Horse coal field, Sheridan and Campbell Counties: U.S.G.S. open-file rept. Pls. 1 and 2, 1:31,680.

304. 1953. Mapel, W.J., Schopf, J.M., and Gill, J.R., A thick coal bed near Lake De Smet, Johnson County: U.S.G.S. Circ. 228, Pl. 1, 1:62,500.

307. 1953. Laramie Basin, Wyo., and North Park, Colo.: Wyoming Geol. Assoc. and Univ. Wyaning 8th annual field conference guidebook. (a) Tectonic map of portions of southern Wyoming and northern Colorado in pocket, 1:375,000, D.L. Blackstone, Jr., structure map of Laramie Basin in pocket, 1:250,000 (Part of area), map p. 58, 1:500,000, J.R. Bergstrom (part of area), map p. 112, 1:250,000, A.F. Hagner (part of area); (b) pocket map of geology along west-central flank of the Laramie Range, 1:62,500, M.S. Tudor (also Wyaning Univ. thesis map, 1: 31,680, 1952); (c) map p. 104, 1:125,000, John de la Montagne; (d) map p. 136, 1:48,000, H.R. Van Gilder; (e) map p. 143, 1:48,000, H.R. Van Gilder. (Geologlc map of Albany County in pocket, 1:187,500, David Love and J.L. Weitz, is same as No. 175; map p. 83, 1:375,000, Brainerd Mears, Jr., is similar to No. 182).

309. 1953. Rapp, J.R., Reconnaissance of the geology and ground-water resources of the La Prele area, Converse County: U.S.G.S. Circ. 243. p. 1., 1:50.000..

B-4 REFERENCES TO GEOLOGIC MAPPING, POWDER RIVER BASIN, WYOMING, 1954-1970

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3. Hose, R.K., 1955, Geology of the Crazy Woman Creek area, Johnson County, Wyo.: U.S. Geol. Survey Bull. 1027-B. Pl. 6, 1:48,000.
Palmquist, J.C., 1967, Structural Analysis of the Horn area, Bighorn Mountains, Wyo.: Geol. Soc. America Bull., v. 78, no. 2, p. 283-298. Pl. 1. 1:48,000.

5. Horn, G.H., 1955, Geologic and structure map of the Sussex and Meadow Creek oil fields and vicinity, Johnson and Natrona Counties, Wyo.: U.S. Geol. Survey Oil and Gas Inv. Map OM-164. 1:31,680.

27. Richardson, E.E., 1957, Geologic and structure contour map of the Tisdale Anticline and vicinity, Johnson and Natrona Counties, Wyo.: U.S. Geol. Survey Oil and Gas Inv. Map OM-194. 1:31,680.

29. Olive, W.W., 1957, The Spotted Horse coalfleld, Sheridan and Campbell Counties, Wyo.: U.S. Geol. Survey Bull. 1050. Pls. 1 and 2, 1:63,360.

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38. Kohout, F.A., 1957, Geology and ground-water resources of the Kaycee irrigation project, Johnson City, Wyo.: U.S. Geol. Survey Water-Supply Paper 1360-E. Pl. 22, 1:35,000.

45. Mapel, W.J., 1959, Geology and coal resources of the Buffalo-Lake de Smet area, Johnson and Sheridan Counties, Wyo.: U.S. Geol. Survey Bull. 1078. Pl. 1, 1:48,000.

48. Horn, G.H., 1959, Geologic and structure map of the Sage Spring Creek oil field and vicinity, Natrona and Converse Counties, Wyo.: U.S. Geol. Survey open-file map. 1:24,000.

49. Horn, G.H., 1959, Geological and structure map of Teapot Dome and vicinity, Natrona County, Wyo.: U.S. Geol. Survey open-file map. 1:24,000.

50. Horn, G.H., and Richardson, E.E., 1959. Area1 geology of the west Sussex oil field, Johnson County, Wyo.: U.S. Geol. Survey open-file map. 1:24,000.

51. Horn, G.H., 1959, Geologic and structure contour map of the west Salt Creek oil field, Natrona County, Wyo.: U.S. Geol. Survey open-file map. 1:24,000.

54. Cserna, E.G., and Rioux, R.L., 1959, Geologic and structure map of the Glenrock area, Natrona and Converse Counties, Wyo.: U.S. Geol. Survey open-file map. 1:48,000.

69. Richardson, E.E., 1961, Geologic and structure map of the North Fork oil field, Kaycee dam, and vicinity, Johnson County, Wyo.: U.S. Geol. Survey Oil and Gas Inv. Map OM-206. 1:24,000.

89. Mapel, W.J., and Pillmore, C.L., 1963, Geology of the Newcastle area, Weston County, Wyo.: U.S. Geol. Survey Bull. 1141-N. Pl. 1, 1:48,000.

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Whitcomb, H.A., and Morris, D.A., 1964, Ground-water resources and geology of northern and western Crook County, Wyo.: U.S. Geol. Survey Water-Supply Paper 1698. Pl. 2, 1:96,000.

Mapel, W.J., Robinson, C.S., and Theobald, P.K., 1959, Geologic and structure contour map of the northern and western flanks of the Black Hills, Wyo., Mont., and S. Dak.: U.S. Geol. Survey Oil and Gas Inv. Map OM-191. 1:96,000.

126. Sharp, W.N., and Gibbons, A.B., 1964, Geology and uranium deposits of the southern part of the Powder River basin, Wyoming: U.S. Geol. Survey Bull. 1147-D. Pl. 1 (2 parts), 1:62,500.

136. Sharp, W.N., McKay, E.J., McKeown, F.A., and White, A.M., 1964, Geology and uranium deposits of the Pumpkin Buttes area of the Powder River Basin, Wyoming: U.S. Geol. Survey Bull. 1107-H. Pl. 11 (2 parts), 1:24,000.

Sharp, W.N., and White, A.M., 1957, Preliminary geologic map of the Pumpkin Buttes area, Campbell and Johnson Counties, Wyo., showing location of uranium occurrences: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-98. 1:24,000.

148. Whitcomb, H.A., 1965, Ground-water resources and geology of Niobrara County, Wyo.: U.S. Geol. Survey Water Supply Paper 1788. Pl. 1, 1:125,000.

155. Davis, J.C., 1965, Bentonite deposits of the Clay Spur district, Crook and Weston Counties, Wyo.: Wyoming Geol. Survey Prelim. Rept. 4. Pl. 1, 1:90,000.

160. Lowry, M.E., and Cummings, T.R., 1966, Ground-water resources of Sheridan County, Wyo.: U.S. Geol. Survey Water-Supply Paper 1807. Pl. 1, 1:125,000.

161. Whitcomb, H.A., Cummings, T.R., and McCullough, R.A., 1966, Ground-water resources and geology of northern and central Johnson County, wyo.: U.S. Geol. Survey Water-Supply Paper 1806. Pl. 1, 1:125,000.

207. Crist, M.A., and Lowry, M.E., 1968, Ground-water resources of Natrona County, Wyo.: U.S. Geol. Survey open-file rept. Fig. 7, 1:125,000.

Wyoming Geological Association, 1954, Guidebook, 9th annual field conference, Casper area, Wyoming, 1954. Geologic map of Natrona County, by J.L. Weitz, J.D. Love, and S.A. Harbison, 1:245,000. Also others maps.

211. Hudson, R.F., 1969, Structural geology of the Piney Creek thrust area, Bighorn Mountains, Wyo.: Geol. Soc. America Bull., v. 80, no. 2, p. 283-295. Pl. 1, 1:50,000 approx.

## APPENDIX C

## SELECTED REFERENCES TO RECENT MAPPING IN THE POWDER RIVER BASIN

C-1 INDEXES TO RECENT MAPPING BY U.S.G.S. AND W.G.S; REGIONAL STUDIES AT VARIOUS SCALES

C-1.1 Coal Studies, U.S.G.S.

C-2. Coal resources of Montana, by J.X. Combo, C.N. Holmes, and H.R. Christner, 1950. Scale, 1:500,000. 2 sheets.

C-6. Coal resources map of Wyoming, by H.L. Berryhill, Jr., D.M. Brown, R.N. Burns, and J.X. Combo. 1951. Scale 1:500,000.

C-23. Geology and coal resources of the Lake De Smet area, Johnson County, Wyo., by W.J. Mapel. 1954 [1955]. Scale, 1:48,000.

C-75. Geologic map and coal resources of the Ranchester quadrangle, Sheridan County, Wyo., and Big Horn County, Mont., by B.E. Barnum. 1975. Lat 44° 52'30" to 45°, long 107° 07'30" to 107° 15'. Scale 1:24,000. 1 sheet.

C-76. Geologic map and coal resources of the Pleasantdale quadrangle, Campbell County, Wyoming, by S.L. Grazis. 1977. Lat 44° to 44° 07'30", long 105° 37'30" to 105° 45'. Three sheets. Scale 1:24,000.

C-77. Geologic map and coal resources of the Scaper Reservoir quadrangle, Campbell County, Wyoming, by S.L. Grazis. 1977. Lat 44° to 44° 07'30", long 105° 30" to 105° 37'30". Three sheets. Scale 1:24,000.

C-78. Geologic map and coal resources of The Gap SW quadrangle, Campbell County, Wyoming, by S.L. Grazis. 1977. Lat 44° to 44° 07'30", long 105° 22'30" to 105° 30'. Three sheets. Scale 1:24,000.

C-79. Geologic map and coal resources of the Saddle Horse Butte quadrangle, Campbell County, Wyoming, by S.L. Grazis. 1977. Lat 44° to 44° 07'30", long 105° 15' to 105° 22' 30". Three sheets. Scale 1:24,000.

C-81-A. Structure contour maps of the Canyon and associated coal beds, western half of the Recluse 1° by 1/2° quadrangle, Campbell County, Wyoming, by B.H. Kent and B.E. Munson. 1978. Scale 1:100,000.

C-81-B. Isopach maps of the Canyon and associated coal beds, western half of the Recluse 1° by 1/2° quadrangle, Campbell County, Wyoming, by B.H. Kent and B.E. Munson. 1978. Scale 1:100,000.

Coal fields of the United States (excluding Alaska and Hawaii). Sheet 1, by James Trumbull. 1959 (1960). Scale 1:5,000,000.

Montana Bureau Mines and Geology - Index Map and Bibliography of coal studies in Montana, by John M. Pinchock, 1976, Special Publication 71.

Open File 1972. Reconnaissance map showing some coal and clinker beds in the Fort Union and Wasatch Formations in the Powder River Basin, Campbell and Converse Counties, Wyoming, by E.M. Schell and G.D. Mowat, 1972, Scale, 1:125,000.

MF-590. Stripping coal deposits of the northern Great Plains, Mont., Wyo., N. Dak., and S. Dak., 1974. Lat 43$^{o}$ to 49$^{o}$, long 100$^{o}$ to 109$^{o}$. Scale 1:1,000,000.

MF-960. Lower Tertiary coal bed distribution and coal resources of the Reno Junction-Antelope Creek area, Campbell Converse, Niobrara, and Weston Counties, Wyoming, by N.M. Denson, J.H. Dover, and L.M. Osmonson. 1978 (1979). Lat about 43$^{o}$ 20' to about 43$^{o}$ 50', long about 105$^{o}$ to about 105$^{o}$ 40'. Scale 1:250,000.

MF-961. Structure contour and isopach maps of the Wyodak-Anderson coal bed in the Reno Junction-Antelope Creek area, Campbell and Converse Counties, Wyoming, by N.M. Denson, J.H. Dover, and L.M. Osmonson. 1978. Scale 1:125,000.

MF-1045. Preliminary geologic map of principal coal beds in the western part of the Recluse 1$^{o}$ by 1/2$^{o}$ quadrangle, Campbell County, Wyoming, by B.H. Kent and B.E. Munson. 1978 (1979). Lat 44$^{o}$ 30' to 45$^{o}$. long 105$^{o}$ to 106$^{o}$. Scale 1:100,000.

I-848-C. Coal resources of the Gillette area, Wyoming, by N.M. Denson, W.R. Keefer, and G.H. Horn. 1973 (1974). Lat 44$^{o}$ to 44$^{o}$ 30', long 105$^{o}$ 10' to 105$^{o}$ 40'. Scale 1:124,000.

I-848-D. Map of the Wyodak-Anderson coal bed in the Gillette area, Campbell County, Wyo., by N.M. Denson and W.R. Keefer. 1974. Lat 44$^{o}$ to 44$^{o}$ 30', long 105$^{o}$ 20' to 105$^{o}$ 40'. Scale 1:125,000.

## C-1.2 Miscellaneous Geological Studies, USGS and Wyoming Geological Survey (WGS)

Wyoming Geological Survey - Geologic map atlases and summary of economic resources (geology, petroleum, coal, minerals, water, stratigraphy, land use, land forms, vegetation).

Counties:

Converse (County Resource Series CRS-1) 22p, 1972
Campbell (County Resource Series CRS-3) 9 pls, 1974
Johnson (County Resource Series CRS-4) 9 pls, 1976
Sheridan (County Resource Series CRS-5) 9 pls, 1978

U.S. Geological Survey and American Assocation of Petroleum Geologists, 1962, Tectonic map of the United States.

1949 Map showing Paleocene deposits of the Rocky Mountains and Plains, by R.W. Brown, 1949.

MF-127. Preliminary tectonic map of Wyoming east of the overthrust belt, showing the distribution of uranium deposits, compiled by F.W. Osterwald and B.G. Dean. 1958. Scale 1:500,000.

MF-806. Preliminary geologic map of the Buffalo area, northwest Powder River Basin, Wyoming, by S.P. Kanizay, S.L. Obernyer, and J.M. Cattermole. 1976 (1977). Lat 44° 07'30" to 44° 37'30", long 106° 30' to 106° 52'30". Scale 1:50,000.

MF-883. Geologic map of the Newcastle 1° by 2° quadrangle, northeastern Wyoming and western South Dakota, compiled by J.D. Love, A.C. Christiansen, and L.W. McGrew. 1977. Lat 43° to 44°, long 104° to 106°. Scale 1:250,000.

MF-1043. Preliminary geologic map of the Sheridan area, northwestern Powder River basin, Wyoming, by S.P. Kanizay, 1978. Lat 44° 37'30" to 45°, long 106° 45' to 107° 15'. Scale 1:50,000.

76-162. Map of alluvial valley floors and strippable coal in forty-two 7-1/2-minute quadrangles, Big Horn, Rosebud, and Powder River Counties, southeast Montana, by H.E. Malde and J.M. Boyles, 2 p., 43 pls., 1 table.

76-176. Isopach map of the Lebo Shale Member, Fort Union Formation, northwestern Powder River basin, Wyoming and Montana, by B.E. Law. 1 isopach map, scale approx. 1:250,000.

78-343. Preliminary geologic map of the Gillette 1° by 2° quadrangle, northeastern Wyoming and western South Dakota, by J.D. Love, A.C. Christiansen, and L.W. McGrew. 8 p., 1 pl., scale 1:250,000.

78-456. Preliminary geologic map of the Sheridan 1° by 2° quadrangle, northern Wyoming, by J.D. Love, A.C. Christiansen and J.L. Earle, compilers, 6 p., 2 pls.

78-493. Preliminary geologic map of the Ekalaka $1^{o}$ by $2^{o}$ quadrangle, southeastern Montana and western North and South Dakota, by R.B. Colton, S.T. Whitaker, W.C. Ehler, J. Helligan, and .G. Bowles, 5 p. 1 pl., scale 1:250,000.

78-506. Geology and coal resources of the Hanging Woman Creek EMRIA site, Big Horn and Powder River Counties Montana, by W.C. Culbertson, J.R. Hatch, and R.H. Affolter, 42 p., 4 pls., 1 fig.

78-614. Preliminary geologic map of the Pumpkin Creek EMRIA Study Site, Elder Creek, Leslie Creek, Coalwood, and Olive quadrangles, Powder River County, Montana, by Marquerite Glenn, 1 pl., scale 1:24,000.

78-897. Locality and structure contour maps of the Pumpkin Creek EMRIA study site, Powder River Country, Montana, by Marguerite Glenn, 8 pls., scale 1:24,000.

78-905. Maps showing formation temperatures and configurations of the tops of the Minnelusa Formation and the Madison Limestone, Powder River Basin, Wyoming, Montana, and adjacent areas by W.J. Head, K.T. Kilty, and R.K. Knottek, 2 pls. scale 1:1,000,000.

78-998. Preliminary geologic map of the Crow Reserve area. Big Horn County, Montana by W. Mapel. 1 pl., scale 1:24,000.

OM-133. Structure contour map of the Powder River Basin, Wyoming and Montana, by W.G. Pierce and R.M. Girard, 1945. Revised by A.D. Zapp. 1951 (1952). Lat $43^{o}$ to $45^{o}$, long $104^{o}30'$ to $107^{o}00'$. Scale 1:316,800.

OM-175. Map of Wyoming showing test wells for oil and gas, anticlines, oil and gas fields, and pipelines, compiled by L.W. McGrew. 1955 (1956). Scale 1:500,000.

OM-178 B. Structure contour map of the Montana plains, by C.E. Dobin and C.E. Erdman, 1955.

OM-191. Geologic and structure contour map of the northern and western flanks of the Black Hills, Wyo., Mont., and S. Dak., by W.J. Mapel, C.S. Robinson, and P.K. Theobald. 1959. Scale 1:96,000. 2 sheets.

OM-202. The Bighorn dolomite and correlative formations in southern Montana and northern Wyoming, by P.W. Richards and C.L. Nieschmidt. 1961. Lat $44^{o}$ to $46^{o}$, long $105^{o}$ to $111^{o}$. Scale, 1:750,000. 2 sheets.

I-847-A. Energy resources map of the Powder River Basin, Wyo. and Mont., compiled by W.R. Keefer and P.W. Schmidt. 1973 (1974). Lat $43^{o}$ to $46^{o}$, long $105^{o}$ to $107^{o}$. Scale 1:500,000.

I-847-D. Geology and water-yielding characteristics of rocks of the northern Powder River Basin, southeastern Montana, by B.D. Lewis and R.S. Roberts. 1978. Two sheets. Lat $45^{o}$ to $46^{o}44'30"$, long $105^{o}$ to $107^{o}25'30"$. Scale 1:250,000.

I-877. Geologic and structure map of the southern part of the Powder River Basin, Converse, Niobrara, and Natrona Counties, Wyo., by N.M. Denson and G.H. Horn. 1975. Two sheets: west part lat about $42^{o}45'$ to $43^{o}15'$, long about $105^{o}$ to about $106^{o}$; east part, lat about $42^{o}45'$ to $43^{o}15'$, long $104^{o}15'$ to $104^{o}45'$. Scale 1:125,000.

HA-465. Water resources of the Powder River basin and adjacent areas, northeastern Wyoming, by W.G. Hodson, R.H. Pearl, and S.A. Druse. 1973 (1974). Lat $43^{o}$ to $45^{o}$, long $104^{o}$ to $107^{o}45'$. Sheets 1 and 2, scale 1:250,000. Sheet 4, scale 1:750,000. 4 sheets.

HA-468. Water resources of the northern Cheyenne Indian reservation and adjacent area, southeastern Montana, by W.B. Hopkins. 1973. Two sheets: lat $45^{o}$ to $45^{o}40'$, long $106^{o}$ to $107^{o}$. Scale 1:125,000.

77-75. Geology and water-yielding characteristics of rocks of the northern Powder River basin, southeastern Montana, by B.D. Lewis and R.S. Roberts, 40 p., 2 pls., scale 1:250,000.

78-237. Water resources of the central Powder River area of southeastern Montana, by W.R. Miller. 114 p., 4 pls., 17 figs., 14 tables.

79-343. Water resources of the southern Powder River area of southeastern Montana, by W.R. Miller. 140 p., 4 pls., 21 figs., 12 tables.

I-847-C. Map showing configuration and thickness and potentiometric surface and water quality in the Madison Group, Powder River basin, Wyoming and Montana, by F.A. Swenson, W.R. Miller, W.G. Hodson and F.N. Visher. 1976. Two sheets: Lat about $43^{o}$ to about $46^{o}$, long about $104^{o}$ to $108^{o}$. Scale: 1:1,000,000.

I-847-D. Geology and water-yielding characteristics of rocks of the 4northern Powder River basin, southeastern Montana, by B.D. Lewis and R.S. Roberts, 1978. Two sheets, lat $45^{o}$ to $46^{o}44'30"$, long $105^{o}$ to $107^{o}25'30"$, scale 1:250,000.

I-848-E. Maps showing occurrence of ground water in the Gillette area, Campbell County, Wyo., by N.J. King. 1974 (1975). Lat $44^{o}$ to $44^{o}30'$, long $105^{o}10'$ to $105^{o}40'$. Scale 1:125,000.

## C-2 INDEXES TO RECENT MAPPING BY USGS, 7-1/2' QUADRANGLES, SCALE 1:24,000

### C-2.1 Geologic Maps and Coal Sections

MF-98. Preliminary geologic map of the Pumpkin Buttes area, Campbell and Johnson Counties, Wyo., showing location of uranium occurrences, by W.N. Sharp and A.M. White. 1957. Scale 1:24,000. 3 sheets.

MF-544. Preliminary geologic map of the Croton 1 SW quadrangle, Campbell County, Wyo., by P.T. Hayes. 1973 (1974). Sheet 1, lat 44°45' to 44°52'30", long 105°37'30" to 105°45'. Scale 1:24,000. 2 sheets.

MF-545. Preliminary geologic map of the Townsend Spring quadrangle, Campbell County, Wyo., by R.J. McLaughlin and P.T. Hayes. 1973 (1974). lat 44°22'30" to 44°30'30", long 105°37'30" to 105°45', scale 1:24,000. 2 sheets.

MF-723. Preliminary geologic map and coal sections of the Wyarno quadrangle, Sheridan County, Wyo., by W.C. Culbertson. 1975 (1976). Lat 44°45' to 44°52'30", long 106°45' to 106°52'30". Scale 1:24,000. 2 sheets.

MF-726. Preliminary geologic map and coal sections of the Jones Draw quadrangle, Sheridan County, Wyo., W.C. Culbertson and M.C. Klett. 1975 (1976). Lat 44°45' to 44°52'30", long 106°37'30" to 106°45'. Scale 1:24,000. 2 sheets.

MF-727. Preliminary geologic map and coal sections of the SR Springs quadrangle, Sheridan County, Wyo., by W.C. Culbertson and M.C. Klett. 1975 (1976). Lat 44°45' to 44°52'30", long 106°30' to 106°37'30". Scale 1:24,000. 2 sheets.

MF-731. Preliminary geologic map and coal sections, ULM quadrangle, Sheridan County, Wyo., by W.J. Mapel and B.W. Dean. 1976. Lat 44°37'30" to 44°45', long 106°30' to 106°37'30". Scale 1:24,000. 2 sheets.

MF-732. Geologic map and coal sections of the Recluse quadrangle, Campbell County, Wyo., by B.H. Kent. 1976. Lat 44°37'30" to 44°45', long 105°37'30" to 105°45'. Scale 1:24,000. 2 sheets.

MF-735. Geologic map and coal sections of the Wildcat quadrangle, Campbell County, Wyo., by B.H. Kent. 1976. Lat 44°30'30" to 44°37'30", long 105°37'30" to 105°45'. Scale 1:24,000. 2 sheets.

MF-762. Geologic map and coal sections of the Verona quadrangle. Sheridan County, Wyoming, by W.J. Mapel and B.W. Dean. 1976. Lat 44°37'30" to 44°45', long 106°37'30" to 106°45'. Scale 1:24,000. 2 sheets.

MF-763. Geologic map and coal sections of the Bar N Draw quadrangle, Wyoming and Montana, by W.J. Mapel. 1976. Lat 44°52'30" to 45°, long 106°45' to 106°52'30". Scale 1:24,000. 2 sheets.

MF-792. Geologic map and coal sections of the Buffalo Run Creek quadrangle, Sheridan County, Wyoming, by W.J. Mapel and M.D. Malahy. 1976. Lat 44°37'30" to 44°45', long 106°45' to 106°52'30". Scale 1:24,000.

MF-801. Preliminary surficial and bedrock geologic map of the Big Horn quadrangle, Sheridan County, Wyoming, by W.F. Ebaugh. 1976. Lat 44°37'30" to 44°45', long 106°52'30" to 107°. Scale 1:24,000.

MF-802. Preliminary geologic map and coal sections of the Willow Crossing quadrangle, Rosebud and Powder River Counties, Montana, by E.J. McKay. 1976. Lat 45°30' to 45°37'30", long 106°07'30" to 106°15'. Scale 1:24,000.

MF-807. Preliminary geologic map and coal sections of the Fort Howes quadrangle, Rosebud and Powder River Counties, Montana, by E.J. McKay. 1976. Lat 45°15' to 45°22'30", long 106°07'30" to 106°15'. Scale 1:24,000.

MF-813. Geologic map and coal sections of the Birney quadrangle, Rosebud County, Montana, by W.J. Mapel. 1976. Two sheets. Lat 45°15' to 45°22'30", long 106°30' to 106°37' 30". Scale 1:24,000.

MF-814. Geologic map and coal sections of the Browns Mountain quadrangle, Montana, by W.C. Culbertson and M.C. Klett. 1976 (1977). Two sheets: lat 45°15' to 45°22'30", long 106°22'30" to 106°30'; scale 1:24,000.

MF-817. Preliminary geologic map and coal sections, King Mountain quadrangle, Rosebud and Powder River Counties, Montana, by E.J. McKay. 1976 (1977). Two sheets: lat 45° 22'30" to 45°30', long 106°07'30" to 106°15'; scale 1:24,000.

MF-822. Geologic map and coal sections of the Stroud Creek quadrangle, Rosebud and Big Horn Counties, Montana, by W.C. Culbertson, W.J. Mapel, and M.C. Klett. 1976 (1977). Lat 45°07'30" to 45°15', long 106°22'30" to 106°30'. Scale 1:24,000.

MF-826. Geologic map and coal sections of the Croton quadrangle, Campbell County, Wyoming, by D.R. Haddock, B.H. Kent, and B.F. Bohor. 1976 (1977). Lat 44°30' to 44°37'30", long 105°52'30" to 106°. Scale 1:24,000.

MF-832. Geologic map and coal sections of the Lacey Gulch quadrangle, Big Horn and Rosebud Counties, Montana, by J.C. Sarnecki. 1977. Two sheets: lat 45°07'30" to 45°15', long 106°30' to 106°37'30". Scale 1:24,000.

MF-917. Geologic map and coal sections of the Truman Draw quadrangle, Campbell County, Wyoming, by B.H. Kent, D.R. Haddock, and B.F. Bohor. 1977 (1978). Two sheets. Lat 44°30' to 44°37'30", long 105°45' to 105°52'30". Scale 1:24,000.

MF-974. Geologic map and coal deposits of the Gillette West quadrangle, Campbell County, Wyoming, by B.E. Law, 1978. Two sheets. Lat 44°15' to 44°22'30", long 105°30' to 105°37'30". Scale 1:24,000.

MF-1014. Geologic map and coal sections of the Pine Butte School quadrangle, Big Horn County, Montana, by W.J. Mapel. 1978. Two sheets. Lat 45° to 45°07'30", long 106°30' to 106°37'30". Scale 1:24,000.

MF-1018. Preliminary geologic map of the Sheridan quadrangle, Sheridan County, Wyoming, by E.N. Hinrichs. 1978. Lat 44°45' to 44°52'30", long 106°52'30" to 107°. Scale 1:24,000.

MF-1055. Preliminary geologic map of the Hultz Draw quadrangle, Sheridan County, Wyoming, by E.N. Hinrichs. 1979. Lat 44°45' to 44°52'30", long 107° to 107°07'30". Scale 1:24,000.

1972 - Preliminary geologic map and coal resources of the Decker quadrangle, Big Horn County, Montana, by B.E. Law and S.L. Grazis, 3 sheets.

74-24. Preliminary geologic map and coal resources of the Gap SW quadrangle, Campbell County, Wyo., by S.L. Grazis. 2 pls., scale 1:24,000.

74-26. Preliminary geologic map and coal resources of the Kicken Creek quadrangle, Campbell County, Wyo., by S.L. Grazis. 2 pls., scale 1:24,000.

74-36. Preliminary geologic map and coal resources of the Fortin Draw quadrangle, Campbell County, Wyo., by B.E. Law. 1974. 2 sheets, scale 1:24,000.

74-98. Preliminary geologic map and coal resources of the Gap quadrangle, Campbell County, Wyo., by G.L. Galyardt. 3 pls., (1 map, 2 sheets of coal sections), scale 1:24,000.

74-172. Preliminary geologic map of the Bertha 2 NE quadrangle, Campbell County, Wyo., by E.J. McKay and E.R. Landis. 2 pls., scale 1:24,000.

74-173. Preliminary geologic map of the Bertha 2 NW quadrangle, Campbell County, Wyo., by E.J. McKay. 3 pls., scale 1:24,000.

74-174. Preliminary geologic map of the Bertha 3 NW quadrangle, Campbell County, Wyo., by E.J. McKay. 3 pls., scale 1:24,000.

74-350. Preliminary geologic map and coal resources of the Coyote Draw quadrangle, Campbell County, Wyo., by G.L. Galyardt. 1974. 3 p., scale 1:24,000.

75-195. Preliminary geologic map and coal resources of the Oriva quadrangle, Campbell County, Wyo., by B.E. Law. 2 p., scale 1:24,000.

78-455. Geologic map and coal sections of the Ucross quadrangle, Sheridan County, Wyoming, by W.J. Mapel. 2 pls., scale 1:24,000.

78-793. Geologic map and coal sections of the northern part of the Horse Hill quadrangle, Sheridan County, Wyoming, by W.J. Mapel. 1 pl., scale 1:24,000.

78-890. Preliminary geologic map of the Buffalo quadrangle, Johnson County, Wyaning, by Ernest Dobrovolny. 1 pl., scale 1:24,000.

## C-2.2 Coal Resource Occurrence and Coal Development Potential Maps

76-387. Preliminary report on coal resources of the Otter Creek EMRIA site, Powder River County, Montana, by E.J. McKay, J.R. Hatch, and E.R. Landis. 49 p., 1 pl., 3 figs., 10 tables.

76-553. Preliminary coal resource occurrence map of the Wyodak bed in The Gap SW quadrangle, Campbell County, Wyoming, by Juliana Waring. 3 p. text, 1 fig., 1 table. scale 1:24,000.

77-57. Coal resource occurrence map of the Little Thunder Reservoir quadrangle, Campbell County, Wyoming, by G.C. Martin. 19 p., 14 pls.

77-58. Coal development potential map of the Little Thunder Reservoir quadrangle, Campbell County, Wyoming, by G.C. Martin. 19 p., 2 pls.

78-30. Coal resource occurrence and coal development potential maps of the Birney quadrangle, Rosebud County, Montana, by W.J. Mapel and B.K. Martin. 24 p., 44 pls., 2 tables, scale 1:24,000.

78-37. Coal resource occurrence and coal development potential maps of the Lacey Gulch quadrangle, Rosebud County, Montana, by W.J. Mapel, B.K. Martin, and B.A. Butler. 31 p., 49 pls., 2 tables, scale 1:24,000.

78-38. Coal resource occurrence and coal development potential maps of the Stroud Creek quadrangle, Rosebud and Big Horn Counties, Montana, by W.J. Mapel, B.K. Martin, and B.A. Butler. 34 p., 54 pls., 4 tables, scale 1:24,000.

78-39. Coal resource occurrence and coal development potential maps of the Browns Mountain quandrangle, Rosebud County, Montana, by W.J. Mapel and B.K. Martin. 39 p., 69 pls., 6 tables, scale 1:24,000.

78-40. Coal resource occurrence and coal development potential maps of the Hamilton Draw quadrangle, Rosebud, Big Horn, and Powder River Counties, Montana, by W.J. Mapel, B.K. Martin, and B.A. Butler. 32 p., 54 pls., 2 tables, scale 1:24,000.

78-41. Coal resource occurrence and coal development potential maps of the southern part of the Clubfoot Creek quadrangle, Rosebud County, Montana, by W.J. Mapel and B.K. Martin. 23 p., 34 pls., 3 tables, scale 1:24,000.

78-64. Coal resource occurrence and coal developent potential of the Cabin Creek Northeast quadrangle, Sheridan and Campbell Counties, Wyoming, and Powder River County, Montana, by IntraSearch, Inc. 21 p., 39 pls., 3 tables, scale 1:24,000.

78-65. Coal resource occurrence and coal development potential of the Black Draw quadrangle, Campbell County, Wyaning, and Powder River County, Montana, by IntraSearch, Inc. 27 p., 39 pls., 3 tables, scale 1:24,000.

78-66. Coal resource occurrence and coal development potential of the Dead Horse Lake quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 29 p., 39 pls., 3 tables, scale 1:24,000.

78-67. Coal resource occurrence and coal development potential of the Corral Creek quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 28 p., 39 pls., 3 tables, scale 1:24,000.

78-631. Coal resource occurrence map and coal development potential of the Iron Spring quadrangle, Big Horn and Treasure Counties, Montana, by Colorado School of Mines Research Institute. 8 p., 3 pls., scale 1:24,000.

78-632. Coal resource occurrence map and coal development potential of the Iron Spring SW quadrangle, Big Horn County, Montana, by Colorado School of Mines Research Institute. 9 p., 3 pls., scale 1:24,000.

78-633. Coal resource occurrence map and coal development potential of the Padlock Ranch quadrangle, Big Horn County, Montana, by Colorado School of Mines Research Institute. 9 p., 3 pls., scale 1:24,000.

78-634. Coal resource occurrence map and coal development potential of the Beebe SW quadrangle, Custer County, Montana, by Colorado School of Mines Research Institute. 8 p., 3 pls., scale 1:24,000.

78-635. Coal resource occurrence and coal development potential maps of the Miller Creek quadrangle, Custer County, Montana, by Colorado School of Mines Research Institute. 16 p., 7 pls., 2 tables, scale 1:24,000.

78-636. Coal resource occurrence and coal development potential maps of the Moon Creek School quadrangle, Custer County, Montana, by Colorado School of Mines Research Institute. 14 p., 7 pls., 1 table, scale 1:24,000.

78-637. Coal resource occurrence and coal development potential maps of the Miller Creek NW quadrangle, Rosebud and Custer Counties, Montana, by Colorado School of Mines Research Institute. 17 p., 7 pls., 1 table, scale 1:24,000.

78-638. Coal resource occurrence and coal development potential maps of the H S School quadrangle, Custer County, Montana, by Colorado School of Mines Research Institute. 16 p., 7 pls., 1 table, scale 1:24,000.

78-639. Coal resource occurrence and coal development potential maps of the Jack Creek quadrangle, Custer County, Montana, by Colorado School of Mines Research Institute. 16 p., 8 pls., 1 table, scale 1:24,000.

78-640. Coal resource occurrence and coal development potential maps of the Fourmile Creek quadrangle, Custer County, Montana, by Colorado School of Mines Research Institute. 16 p., 8 pls., 1 table, scale 1:24,000.

78-64 1. Coal resource occurrence and coal development potential maps of the McKerlich Creek quadrangle, Rosebud County, Montana, by Colorado School of Mines Research Institute. 15 p., 10 pls., 1 table, scale 1:24,000.

78-642. Coal resource occurrence and coal development potential maps of the Brandenberg NW quadrangle, Custer and Rosebud Counties, Montana, by Colorado School of Mines Research Institute. 17 p., 7 pls., 1 table, scale 1:24,000.

78-643. Coal resource occurrence and coal development potential maps of the John Hen Creek quadrangle, Rosebud County, Montana, by Colorado School of Mines Research Institute. 18 p., 10 pls., 1 table, scale 1:24,000.

78-644. Coal resource occurrence and coal development potential maps of the Crain Place quadrangle, Rosebud County, Montana, by Colorado School of Mines Research Institute. 18 p., 11 pls., 1 table, scale 1:24,000.

78-645. Coal resource occurrence and coal development potential maps of the Hamnond Draw NW quadrangle, Rosebud County, Montana, by Colorado School of Mines Research Institute. 18 p., 10 pls., 1 table, scale 1:24,000.

78-646. Coal resource occurrence and coal development potential maps of the Miller Creek SW quadrangle, Custer and Rosebud Counties, Montana, by Colorado School of Mines Research Institute. 18 p., 12 pls., 2 tables, scale 1:24,000.

78-647. Coal resource occurrence and coal development potential maps of the Griffin Coulee SW quadrangle, Rosebud and Treasure Counties, Montana, by Colorado School of Mines Research Institute. 17 p., 7 pls., 1 table, scale 1:24,000.

78-648. Coal resource occurrence and coal development potential maps of the Colstrip West quadrangle, Rosebud County, Montana, by Colorado School of Mines Research Institute. 20 p., 13 pls., 1 table, scale 1:24,000.

78-651. Coal resource occurrence and coal development potential maps of the Poker Jim Butte quadrangle, Rosebud and Powder River Counties, Montana, by W.J. Mapel, B.K. Martin, and B.A. Butler. 33 p., 64 pls., 3 tables, scale 1:24,000.

78-653. Coal resource occurrence and coal development potential maps of the Forks Ranch quadrangle, Big Horn County, Montana, by W.C. Culbertson, L.N. Robinson, and T.M. Gaffke. 31 p., 59 pls., 4 tables, scale 1:24,000.

78-654. Coal resource occurrence and coal development potential maps of the Quietus quadrangle, Big Horn and Powder River Counties, Montana, by W.C. Culbertson and L.N. Robinson. 26 p., 44 pls., 4 tables, scale 1:24,000.

78-655. Coal resource occurrence and coal development potential of the Homestead Draw Southwest quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 32 p., 44 pls., 3 tables, scale 1:24,000.

78-829. Coal resource occurrence and coal development potential of the Homestead Draw quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 30 p., 29 pls., 3 tables, scale 1:24,000.

78-831. Coal resource occurrence and coal development potential of the Kline Draw quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 30 p., 34 pls., 3 tables, scale 1:24,000.

78-832. Coal resource occurrence and coal development potential of the Reservoir Creek quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 28 p., 40 pls., 3 tables, scale 1:24,000.

78-833. Coal resource occurrence and coal development potential maps of the Minnehaha Creek South quadrangle, Treasure and Big Horn Counties, Montana, by Colorado School of Mines Research Institute. 21 p., 16 pls., 1 table, scale 1:24,000.

78-834. Coal resource occurrence and coal development potential maps of the McClure Creek quadrangle, Rosebud and Treasure Counties, Montana, by Colorado School of Mines Research Institute. 22 p., 15 pls., 2 tables, scale 1:24,000.

78-835. Coal resource occurrence and coal development potential maps of the Trail Creek School quadrangle, Rosebud County, Montana, by Colorado School of Mines Research Institute. 20 p., 13 pls., 1 table, scale 1:24,000.

78-836. Coal resource occurrence and coal development potential maps of the Colstrip East quadrangle, Rosebud County, Montana, by Colorado School of Mines Research Institute. 18 p., 13 pls., 1 table, scale 1:24,000.

78-837. Coal resource occurrence and coal development potential maps of the Carey-Malone School quadrangle, Custer County, Montana, by Colorado School of Mines Research Intstitute. 20p., 11 pls., 2 tables, scale 1:24,000.

78-838. Coal resource occurrence and coal development potential maps of the Kirkpatrick Hill quadrangle, Custer County, Montana, by Colorado School of Mines Research Institute, 20 p., 10 pls., 2 tables, scale 1:24,000.

79-21. Coal resource occurrence and coal development potential maps of the White Tail Butte quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 30 p., 42 pls. 4 tables, scale 1:24,000.

79-22. Coal resource occurrence and coal development potential maps of the Rocky Butte Southwest quadrangle, Campbell County, Wyoming, by IntraSearch, Inc. 29 p., 24 pls., 3 tables, scale 1:24,000.

79-23. Coal resource occurrence and coal development potential maps of the Larey Draw quadrangle, Campbell County, Wyoming, IntraSearch, Inc. 35 p., 54 pls. 3 tables, scale 1:24,000.

79-24. Coal resource occurrence and coal development potential maps of the Spotted Horse quadrangle, Campbell County, Wyoming, by IntraSearch, Inc., 33 p., 50 pls., 3 tables, scale 1:24,000.

C-2.3 Surficial Geologic Maps

MF-894. Surficial geologic map of the Hilight quadrangle, Campbell County, Wyoming, by D.A. Coates, 1977. Lat 43° 45' to 43° 52' 30", long 105° 22' 30". Scale 1:24,000.

MF-895. Surficial geologic map of the Coyote Draw quadrangle, Campbell County, Wyoming, by D.S. Fullerton, 1977. Lat 44° 07' 30", long 105° 15' to 105° 22' 30". Scale 1:24,000.

MF-896. Surficial geologic map of the Gap SW quadrangle, Campbell County, Wyoming, by D.S. Fullerton and R.M. Kirkham. 1977. Lat 44° to 44° 07' 30", long 105° 30'. Scale 1:24,000.

MF-897. Surficial geologic map of the Gap quadrangle, Campbell County, Wyoming, by D.S. Fullerton and R.M. Kirkham. 1977. Lat 44° 07' 30" to 44° 15', long 105° 22' 30" to 105° 30'. Scale 1:24,000.

MF-898. Surficial geologic map of the Saddle Horse Butte quadrangle, Campbell County, Wyoming, by R.M. Kirkham and D.S. Fullerton. 1977. Lat 44° to 44°07'30", long 105°15' to 105°22'30". Scale 1:24,000.

MF-918. Surficial geologic map of the Appel Butte quadrangle, Campbell County, Wyoming, by D.S. Fullerton. 1977 (1978). Lat 44°07'30" to 44°15', long 105°30' to 105°37'30". Scale 1:24,000.

MF-919. Surficial geologic map of the Corral Creek quadrangle, Campbell County, Wyoming, by D.S. Fullerton. 1977 (1978). Lat 44°52'30" to 45°, long 105°37'30" to 105°45'. Scale 1:24,000.

MF-920. Surficial geologic map of the Scaper Reservoir quadrangle, Campbell County, Wyoming, by D.S. Fullerton. 1977 (1978). Lat 44° to 44°07'30", long 105°30' to 105°37'30". Scale 1:24,000.

MF-929. Surficial geologic map of the Fortin Draw quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°15' to 44°22'30", long 105°15' to 105°22'30". Scale 1:24,000.

MF-938. Surficial geologic map of the Open A Ranch quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat 43°45' to 43°52'30", long 105°07'30" to 105°15'. Scale 1:24,000.

MF-946. Surficial geologic map of the Croton quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44° 30' to 44°37'30", long 105°52'30" to 106°. Scale 1:24,000.

MF-947. Surficial geologic map of the Gillette East quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°15' to 44°22'30", long 105°22'30" to 105°30'. Scale 1:24,000.

MF-948. Surficial geologic map of the Green Hill quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°22'30" to 44°30', long 105°15' to 105°22'30". Scale 1:24,000.

MF-949. Surficial geologic map of the Larey Draw quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°37'30" to 44°45', long 105°52'30' to 106°. Scale 1:24,000.

MF-950. Surficial geologic map of the Moyer Springs quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°22'30" to 44°30', long 105°22'30" to 105°30'. Scale 1:24,000.

MF-951. Surficial geologic map of the Oriva quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44° 15' to 44°22'30", long 105°37'30" to 105°45'. Scale 1:24,000.

MF-952. Surficial geologic map of the Spotted Horse quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°37'30" to 44°45', long 105°45' to 105°52'30". Scale 1:24,000.

MF-953. Surficial geologic map of the Truman Draw quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°30' to 44°37'30", long 105°45' to 105°52'30". Scale 1:24,000.

MF-954. Surficial geologic map of the Reno Reservoir quadrangle, Campbell County, Wyoming, by H.D. Moore and D.A. Coates. 1978. Lat 43°37'30" to 43°45', long 105°15' to 105°22'30". Scale 1:24,000.

MF-955. Surficial map of the Piney Canyon NW quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat 43° 37'30" to 43°45', long 105°07'30" to 105°15'. Scale 1:24,000.

MF-969. Surficial geologic map of the Reno Junction quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat 43°45' to 43°52'30", long 105°22'30" to 105°30'. Scale 1:24,000.

MF-970. Surficial geologic map of the Eagle Rock quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat 43°52'30" to 44°, long 105°22'30" to 105°30'. Scale 1:24,000.

MF-971. Surficial geologic map of the Neil Butte quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat 43°52'30" to 44°, long 105°15' to 105°22'30". Scale 1:24,000.

MF-972. Surficial geologic map of the Rough Creek quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat 43°52'30" to 44°, long 105°07'30" to 105°15'. Scale 1:24,000.

MF-977. Surficial geologic map of the Gillette West quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°15' to 44°22'30", long 105°30' to 105°37'30. Scale 1:24,000.

MF-978. Surficial geologic map of the Rawhide School School quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44° 22' 30" to 44° 30', long 105° 30' to 105° 37' 30". Scale 1:24,000.

MF-979. Surficial geologic map of the Oriva NW quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44° 22'30" to 44°30', long 105°37'30" to 105°45'. Scale 1:24,000.

MF-987. Surficial geologic map of the Piney Canyon SW quadrangle, Campbell County, Wyoming, by D.A. Coates and H.D. Moore. 1978. Lat 43°30' to 43°37'30", long 105°07'30" to 105°15'. Scale 1:24,000.

MF-988. Surficial geologic map of the Recluse quadrangle, Campbell County, Wyoming, by V.S. Williams. 1978. Lat 44°37'30" to 44°45', long 105°37'30" to 105°45'. Scale 1:24,000.

MF-989. Surficial geologic map of the Wildcat quadrangle, Campbell County, Wyoming, by V.S. Williams and Paul McElwain. 1978. Lat 44°30' to 44°37'30", long 105°37'30" to 105°45'. Scale 1:24,000.

MF-1019. Surficial geologic map of the Little Thunder Reserve quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat 43°37'30" to 43°45', long 105°22'30" to 105°30'. Scale 1:24,000.

MF-1020. Surficial geologic map of the Turnercrest NE quadrangle, Campbell County, Wyoming, by D.A. Coates. 1978. Lat about 43°40' to 43°45', long 105°30' to about 105°35'. Scale 1:24,000.

## C-3 ADDITIONAL REFERENCES TO MAPS, CHARTS, AND GEOPHYSICAL LOGS, POWDER RIVER BASIN

### C-3.1 Geological Maps by Wyoming Geological Society Montana Bureau of Mines and Geology and the U.S. Geological Survey

Montana Bureau of Mines and Geology and U.S. Geologial Survey - Ground Water Resources of the Northern Powder River Valley, Southeastern Montana, 1968, Bulletin 66, 34 p., 1 pl.

Montana Bureau of Mines and Geology - Structure contour map, Upper Cretaceous, southeastern Montana, by C.A. Balster, 1973, Special Publication 60.

Montana Bureau of Mines and Geology - Water Resources of the Central Powder River area of southeastern Montana by W.R. Miller, 1979, Bulletin 108, 65 p., 4 pls.

Wyoming Geological Survey - Energy resources map of Wyoming, by G.B. Glass, W.G. Wendall, F.K. Root and R.M. Breckenridge, 1975, scale 1:500,000.

Wyoming Geological Survey - Geological map of Natrona County, Wyoming, by J.L. Weitz, J.D. Love, and S.A. Harbinson, 1954.

Wyoming Geological Survey - Wyoming Mines and Minerals 1979, by W.D. Hausel, G.B. Glass, D.R. Lageson, A.J. VerPloeg, and R.H. DeBruin, 1979, Scale 1:500,000.

U.S. Geological Survey, 1976, Water Resources Investigations in Montana 1976, 1 plate.

U.S. Geological Survey, 1976, Water Resources Investigations in Wyoming 1976, 1 plate.

### C-3.2 Land Use Maps by the USGS

MF-932. Climate appraisal maps of the rehabilitation potential of strippable coal lands in the Powder River basin. Wyoming and Montana, by T.J. Toy and B.E. Munson. 1978. Two sheets. Scale 1:1,000,000.

I-848-A. Land use map of the Gillette area, Wyoming, 1970, by L.M. Shown. 1973. Lat 44° to about 44°30', long 105° 10' to 105°40'. Scale 1:125,000.

I-848-B. Land and coal ownership in the Gillette area, Wyoming, compiled by U.S. Geological Survey. 1973. Lat 44° to 44°30', long 105°10' to 105°40'. Scale 1:250,000.

I-848-F. Map showing some potential effects of surface mining of the Wyodak-Anderson coal, Gillette area, Campbell County, Wyoming, by R.F. Hadley and W.R. Keefer. 1975 (1976). Lat 44° to 44°36'41", long 105°12'18" to 105°47'04". Scale 1:125,000.

74-162. Leasable mineral and waterpower land classification map, Newcastle quadrangle, Wyoming, showing lands withdrawn, classified, and valuable prospectively for leasable minerals and occurrences of other selected minerals, lands withdrawn or classified for waterpower and reservoir sites, compiled by A.F. Bateman, Jr., E.G. Allen, and J.P. Kennedy. 1 map with transparent overlay, scale 1:250,000.

74-164. Leasable mineral and waterpower land classification map, Casper quadrangle, Wyoming, showing lands withdrawn, classified, and valuable prospectively for leasable minerals and occurrences of other selected minerals, lands withdrawn or classified for waterpower and reservoir sites, compiled by A.F. Bateman, Jr., E.G. Allen, J.P. Kennedy, and G.S. Yamamoto. 1 map with transparent overlay, scale 1:250,000.

75-191. Leasable mineral and waterpower land classification map, Ekalaka quadrangle, Montana, showing lands withdrawn, classified, and valuable prospectively for leasable minerals and occurrences of other selected minerals; lands withdrawn or classified for waterpower and reservoir sites, compiled by A.F. Bateman, Jr., E.G. Allen, and G.A. Lutz. Scale 1:250,000.

75-194. Leasable mineral and waterpower land classification map, Miles City quadrangle, Montana, showing lands withdrawn, classified, and valuable prospectively for leasable minerals and occurrences of other selected minerals; lands withdrawn or classified for waterpower and reservoir sites, compiled by A.F. Bateman, Jr., and E.G. Allen. Scale 1:250,000.

76-25. Land use and land cover and associated maps for Miles City, Montana, North Dakota. Lat $46^{\circ}$ to $47^{\circ}$, long $104^{\circ}$ to $106^{\circ}$. This data set consists of four maps keyed to the USGS topographic map Miles City, 1:250,000.

76-434. A map of environmental values as an aid to planning reclamation of surface-mined areas: The Gap quadrangle, Wyoming, by D.W. Moore and J.M. Boyles. 11 p., 2 figs.

77-393. Land use and land cover and associated maps for Hardin, Montana, Wyoming. Lat $45^{\circ}$ to $46^{\circ}$, long $106^{\circ}$ to $108^{\circ}$. This data set consists of five maps keyed to the USGS topographic map Hardin, 1:250,000.

77-659. Land use and land cover and associated maps for Newcastle, Wyoming, South Dakota. Lat $43^{\circ}$ to $44^{\circ}$, long $104^{\circ}$ to $106^{\circ}$. This data set consists of four maps keyed to the USGS topographic map Newcastle, 1:250,000.

77-660. Land use and land cover and associated maps for Gillette, Montana, Wyoming, South Dakota. Lat $44^{\circ}$ to $45^{\circ}$, long $104^{\circ}$ to $106^{\circ}$. This data set consists of four maps keyed to the USGS topographic map Gillette, 1:250,000.

77-661. Land use and land cover and associated maps for Ekalaka, Montana, North Dakota, South Dakota. Lat $45^{\circ}$ to $46^{\circ}$, long $104^{\circ}$ to $106^{\circ}$. This data set consists of four maps keyed to the USGS topographic map Ekalaka, 1:250,000.

78-89. Map showing projected land disturbance by surface mining of coal in Campbell County, Wyoming, by N.J. Noreen and D.W. Moore. 2 pls.

C-3.3 Geophysical Maps and Logs by the USGS

75-661. Airborne gamma-ray spectrometry and aeromagnetic survey of part of the southern Powder River Basin in Converse County, Wyo., by K.A. Schulz. 5 p., 4 pls., 1 fig.

77-621. Aeromagnetic map of part of the southern Powder River basin, Wyoming, by J.S. Duval, J.A. Pitkin, and D.L. Macke. 1 pl.

77-721-C. Geophysical logs for Powder River and Dawson Counties, Montana, chapter C of Preliminary report of 1977 coal drilling in eastern Montana and northeastern Wyoming. 79 p.

77-721-E. Geophysical logs for Campbell and Converse Counties, Wyoming, chapter E of Preliminary report of 1977 coal drilling in eastern Montana and northeastern Wyoming, by U.S. Geological Survey and Montana Bur. of Mines and Geology. 202p.

77-721-F. Geophysical logs for Dawson, McCone, Richland, and Rosebud Counties, Montana, Chapter F of Preliminary report of 1977, coal drilling in eastern Montana and northeastern Wyoming, by U.S. Geological Survey and Montana Bur. of Mines and Geology. 74 p.

MF-956. Aerial gamma-ray maps of part of the southern Powder River Basin in Converse County, Wyoming, by D.L. Macke, J.S. Duval, and J.A. Pitkin. 1978. Two sheets. Lat about 43° to about 43°15', long about 105°30' to about 105°45'. Scale 1:125,000.

C-3.4 Stratigraphic Charts and Sections by the USGS and U.S. ERDA

OC-13. Preliminary stratigraphic sections and thickness maps of Lower Cretaceous and non-marine Jurassic rocks of central Wyoming, by J.D. Love, 1945.

OC-14. Preliminary stratigraphic sections and thickness maps of Jurassic rocks in central Wyoming, by J.D. Love, 1945.

OC-17. Preliminary stratigraphic sections and thickness maps of Triassic rocks in central Wyoming, by J.D. Love, 1945.

OC-32. Preliminary Jurassic formations of Montana, by R.W. Imlay, L.S. Gardner, C.P. Rogers, Jr., and H.D. Hadley, 1948.

OC-36. Stratigraphic sections of pre-Cody, Upper Cretaceous rocks in central Wyoming, by R.M. Thompson, J.D. Love and H.A. Tourtelot, 1949.

OC-44. Stratigraphy and paleontology of Paleozoic rocks, Hartville area, eastern Wyoming, by J.D. Love, L.G. Henbest, and N.M. Denson, 1953.

OC-69. Stratigraphic sections of some Triassic and Jurassic rocks from Douglas, Wyoming, to Boulder, Colorado, by G.N. Pipiringos and R.B. O'Sullivan. 1976.

oc-70. Correlation chart of Cretaceous and Paleocene rocks of the northern Great Plains, by D.D. Rice. 1976 (1977).

oc-71. Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains,-Montana, by D.D. Rice, 1976. Three sheets. Scale 1:500,000.

OC-72. Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, North Dakota and South Dakota, by D.D. Rice. 1977. Three sheets.

OC-73. Stratigraphic diagrams with electric logs of Upper Cretaceous rocks, Powder River basin, Johnson, Campbell and Crook Counties, Wyoming, section A-A', by E.A. Merewether, W.A. Cobban, R.M. Matson, and W.J. Magathan. 1977.

OC-74. Stratigraphic diagrams with electric logs of Upper Cretaceous rocks, Powder River basin, Natrona, Campbell, and Weston Counties, Wyoming, section B-B', by E.A. Merewether, W.A. Cobban, R.M. Matson, and W.J. Magathan. 1977.

oc-75. Stratigraphic diagrams with electric logs of Upper Cretaceous rocks, Powder River basin, Natrona, Converse, and Niobrara Counties, Wyoming, section C-C', by E.A. Merewether, W.A. Cobban, R.M. Matson, and W.J. Magathan. 1977.

OC-76. Stratigraphic diagrams with electric logs of Upper Cretaceous rocks, Powder River basin, Sheridan, Johnson, Campbell, and Converse Counties, Wyoming, section D-D', by E.A. Merewether, W.A. Cobban, R.M. Matson, and W.J. Magathan. 1977.

75-98. Three unedited stratigraphic sections of Cretaceous and Paleocene rocks of the Northern Great Plains, Mont., N. Dakota, and S. Dakota, by D.D. Rice. 5 pls.

75-99. Three unedited stratigraphic sections of Cretaceous and Paleocene rocks of the Northern Great Plains, Mont., by D.D. Rice. 5 pls.

East-west cross-section, southern Powder River Basin, Wyo., by B.K. McKee1 and M.E. Crew, 1972: U.S. ERDA Preliminary Map 24, sheet 2 of 9, open file report.